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ABSTRACT

The goal of the conference reported in this document was to initiate major revitalization of freshman science by bringing together individuals who have been working to improve introductory courses with research faculty who may or may not have been actively involved in the teaching of these courses. This report tries to capture the spirit and the commitment to action which developed at the conference. The following are some points that emerged as a consensus of the participants: (1) science education is such an important national problem that research universities must give it a high priority; (2) science education should accommodate itself to the students and not vice versa; (3) there is notable success and tremendous promise in the undergraduate and outreach programs at research universities, but the success needs to be communicated and moved from the "pilot plant" to the "full production" mode; (4) the walls of the university should come down in order to broaden access and to draw upon the resources of the K-12 system, industry, and the public; (5) the walls between the disciplines should come down to enhance collaboration on the curriculum. Brief summaries of the consensus findings are given in the body of the report. Three of the five appendixes, which make up more than half the document, consist of the following papers: "Student Understanding in Physics: What We Teach and What is Learned," by Lillian C. McDermott; "Improving Academic Performance in Mathematics", by Uri Treisman, and "America at the Crossroads: The Challenge of Science Education," by James J. Duderstadt. The fourth and longest appendix consists of 13 summaries of reports on science and engineering education appearing between 1983 and 1989. The final appendix is a list of participants. A conference schedule is included. (PR)

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ALLIANCE
FOR
UNDERGRADUATE
EDUCATION

THE FRESHMAN YEAR IN SCIENCE AND ENGINEERING
Old Problems, New Perspectives for Research Universities

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A report of a conference sponsored by
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This is the report of the conference sponsored by the Alliance for Undergraduate Education with major support from the National Science Foundation through its Division for Undergraduate Science, Engineering, and Mathematics Education. It was held April 6–7, 1990, at The University of Michigan.

The goal of the conference was to initiate major revitalization of freshman science by bringing together individuals who have been working to improve introductory courses with research faculty who may or may not have been actively involved in the teaching of these courses. Out of this will come both a statement of the problems and an agenda for revitalizing these courses.

The conference consisted of five plenary sessions, led by an invited speaker and a distinguished panel of scientists in each of the areas of mathematics, physics, chemistry, biology and engineering. In addition there were informal workshops to give participants practical strategies for improving introductory science education.

University faculty and other interested persons attended the conference. Most of the participants were science faculty from research institutions. In addition, faculty from comprehensive universities and liberal arts colleges, as well as university administrators and government officials, attended. The list of participants is given in Appendix V.

This report of the conference was written by William R. Wineke, medical reporter for the *Wisconsin State Journal* in Madison, and by the conference organizer, Professor Phillip Certain, Department of Chemistry, University of Wisconsin–Madison. The report strives to capture the spirit and the commitment to action which developed at the conference, but it does not attempt to be complete. Inaccuracies and omissions are the responsibility of the authors.

ALLIANCE
FOR
UNDERGRADUATE
EDUCATION

THE FRESHMAN YEAR IN SCIENCE AND ENGINEERING

Old Problems, New Perspectives for Research Universities

A report of a conference sponsored by
The Alliance for Undergraduate Education with support from
The National Science Foundation

SUMMARY

The following points emerged as a consensus of the participants at the conference. They are discussed in the text of the report.

- Science education is such an important national problem that research universities must give it high priority.
- Science education should accommodate itself to the students and not vice versa.
- There are notable successes and tremendous promise in the undergraduate and outreach programs at research universities, but the successes need to be communicated and moved from the "pilot plant" to the "full production" mode.
- The walls of the university should come down in order to broaden access and to draw upon the resources of the K-12 system, industry and the public.
- The walls between the disciplines should come down to enhance collaboration on the curriculum.
- Important questions should be asked and answered at the departmental level: What is important to know? What can be left out of introductory courses? What incentives do the faculty want to reward exemplary results in teaching?
- Young faculty should be included in the process of change.
- The health of scientific *research* over the next several decades depends upon strong leadership in science and engineering *education* at the federal level, especially within the National Science Foundation.
- The Alliance for Undergraduate Education should create a strong science and engineering focus.

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SCHEDULE OF THE CONFERENCE

Thursday, April 5, 1990

6:30 **Reception and Welcome**
Mary Ann Swain
The University of Michigan
Co-chair, Alliance for Undergraduate Education

Phillip Certain
University of Wisconsin-Madison
Conference Chair

8:00 **Keynote Address: Alliances: Myth, Reality and Expectations**
Bassam Shakhashiri
Assistant Director for Science and Engineering Education
National Science Foundation
While serving as principal education officer of the NSF, he has continued to be active in the development of chemistry demonstrations and hands-on science.

Friday, April 6

8:15 **Welcome**
Edward Alpers
University of California, Los Angeles
Co-chair, Alliance for Undergraduate Education

8:30 **Mathematics**
Speaker: Uri Triesman, University of California, Berkeley
Director of the Dana Center for Innovation in Mathematics and Science Education at the University of California, Berkeley and Eugene Lang Professor of Mathematics Education and Social Change at Swarthmore College. He is noted for his research in the dynamics of minority student performance.
Panelists: Donald Babbitt, University of California, Los Angeles
Naomi Fisher, University of Illinois at Chicago
Nelsen Markley, University of Maryland, College Park

10:15 **Physics**
Speaker: Homer Neal, The University of Michigan
Chairman of the Department of Physics, his research is in elementary particle physics.
Panelists: Judy Franz, West Virginia University
Lillian McDermott, University of Washington
Eugen Merzbacher, University of North Carolina at Chapel Hill

1:15 p.m. **Chemistry**
Speaker: Bradley Moore, University of California, Berkeley
Dean of the College of Chemistry, his research focusses on reaction rate measurements and the fundamentals that control molecular processes.
Panelists: Theodore Brown, University of Illinois at Urbana-Champaign
Daniel Kivelson, University of California, Los Angeles
John Moore, University of Wisconsin-Madison
Albert Thompson, Spelman College

3:00 **Biology**
Speaker: Paul Williams, University of Wisconsin-Madison
Professor of Plant Pathology and Director of the Center for Biology Education, he is the developer of Wisconsin FastPlants, used worldwide in both research and teaching.
Panelists: Robert Goldberg, University of California, Los Angeles
William Jensen,The Ohio State University
Lewis Kleinsmith, The University of Michigan

4:45 **Engineering**
Speaker: Karl Pister, University of California, Berkeley
Roy W. Carlson Professor of Engineering and Dean of the College of Engineering, his research is in the area of mechanics of solids and structures.
Panelists: Ronald Barr, The University of Texas at Austin
John Brighton, The Pennsylvania State University
Denice Denton, University of Wisconsin-Madison

6:15 **Reception and Banquet**
Address: *America at the Crossroads: The Challenge of Science Education*
James J. Duderstadt
President of The University of Michigan and a noted author and researcher in the field of nuclear engineering.

Saturday, April 7

8:30 a.m. **Workshops**
Improving Academic Performance in Biology
Lewis Kleinsmith, The University of Michigan
Improving Academic Performance in Mathematics
Uri Treisman, University of California, Berkeley
Students Understanding Physics: What We Teach and What Is Learned
Lillian McDermott, University of Washington
Freshman Chemistry Curriculum at UCLA
Daniel Kivelson, University of California, Los Angeles
Engineering Graphics
Ronald Barr, University of Texas at Austin
Funding Opportunities in Undergraduate Science and Engineering
Robert Watson, National Science Foundation
Minority Access to Science Education
Albert Thompson, Spelman College
Phillip Certain, University of Wisconsin-Madison
Project Seraphim
John Moore, University of Wisconsin-Madison
New Chemistry Curriculum at the University of Michigan
Seyhan Ege and Brian Coppola, The University of Michigan
Women in Science
Cinda-Sue Davis, The University of Michigan
FastPlants
Paul Williams, University of Wisconsin-Madison
The State of Science and Mathematics Education in the United States
Peter Yankwich, The National Science Foundation

1:00 p.m. **Closing Plenary Session: Where Do We Go From Here?**
Moderator: Phillip Certain, University of Wisconsin-Madison
Mathematics: Richard Hill, Michigan State University
Physics: Sidney Perkowitz, Emory University
Chemistry: David Curtis, The University of Michigan
Biology: Patricia Gensel, University of North Carolina at Chapel Hill
Engineering: David Kauffman, University of New Mexico

3:00 **End of conference**

INTRODUCTION

Three decades ago, when the Soviet Union launched its "Sputnik" space satellite, the shock of a perceived weakening of the United States' advantage in science and engineering so galvanized the American public that it demanded radical change.

The resulting infusion of both material resources and cultural support so strengthened the scientific community that, within 10 years, not only were Americans walking on the moon, but the nation's laboratories and classrooms were filled with bright young men—and a few bright young women—who would form the backbone of the scientific establishment for the next 30 years. Much of the scientific innovation we take for granted today is the product of the study and research of these young scientists.

Society now faces a new crisis in science and engineering, one far more grave than that faced in the 1950s, but, as yet, there has been no new Sputnik to sound the alarm. The crisis is this: Those who have carried the load of scientific advance during the past three decades are nearing retirement age, and the American educational system is producing far fewer scientists and engineers than it will need to maintain its technology and to continue the basic research that underpins the entire scientific and technological engine of the economy. It is also producing far fewer scientists and engineers than it will need to renew the supply of faculty to teach the students of the next century.

Professor Homer Neal, chairman of the Department of Physics of The University of Michigan, has frequently warned Congress and educators that, in spite of the importance of science and engineering to our technology-based society, we have fewer students majoring in science and engineering than ever before. Due to simple demographics, we can expect the overall number of school-age children to decline in the years ahead. The decline in those population groups which have traditionally been our source of science and engineering students will be at an even more dramatic rate.

Those demographics include the following: By 1995, there will be 20 percent fewer 18 year-olds than there were in 1975; if the same percentage of college-age students were to choose majors in science and engineering in the 1990s as did so traditionally, the nation would experience—because of the fewer students in the base population—a cumulative shortfall of 675,000 Bachelor of Science degrees by the year 2000. However, the percentage of students choosing careers in science and engineering is not, in fact, holding constant but is dropping precipitously. This is the "pipeline" problem.

When one looks at American demographics, one other fact needs particular notice: the future pipeline of science and technology in the United States cannot be limited to a largely homogeneous group of white males. Women now pursue careers at roughly the same rate as men, but women do not enter scientific and engineering careers at the same rate as men. According to a recent report of the Task Force on Women, Minorities, and the Handicapped in Science and Technology, women are 51 percent of the population and 45 percent of the workforce, but only 11 percent of all employed scientists and engineers. In 1986, 30 percent of science and engineering bachelor's degrees, 34 percent of Ph.D.'s in the life sciences, 16 percent in the physical sciences and 7 percent in engineering went to women.

Members of minority groups are increasing as a percentage of the overall American population, but a national study of scientific interest among underrepresented minorities shows that of 856,000 high school sophomores in 1977, 86,000 showed an interest in science and engineering studies. Of this group, only 13,000 have graduated from college with majors in science and engineering, and a mere 450 minority men and women of that 1977 pool of 856,000 high school sophomores are expected to receive Ph.D. degrees in science and engineering, according to National Science Foundation estimates. Thus, to refill the science and engineering pipeline, science education at all levels must address itself more effectively to an increasingly diverse population.

As important as the problem posed by a decreasing number of students seeking professions in science and engineering is the danger to the fabric of the American culture itself by citizens who, in Professor

Neal's words, "not only don't know what they should about science, but don't even know that they don't know." This is the problem of scientific literacy.

"One of the fundamental underpinnings of our democracy is the premise of a broadly knowledgeable populace," Professor Neal notes. "If we the people are to make the policy decisions about the directions of this country, it is important that those decisions be made on the basis of knowledge, rather than through ignorance and superstition. Having a large fraction be scientifically illiterate is a cause for concern. Many Americans have almost no grasp of the fundamentals of physics, astronomy, biology, chemistry, nor, for that matter, mathematics. And, what they think they know about these fields is often wrong. There is little embarrassment on their part that they know so little. Indeed, in some circles, it is even a mark of distinction to portray contempt for these fields."

In addition to coping with indifference, the nation must address the rebuilding of the scientific pipeline in a context quite different from the heady days of the early 1960s, before Love Canal, Three Mile Island, the Ozone Hole, and all the other disasters that have tarnished science in the minds of the public. And it must rebuild in the face of a staggering federal deficit.

It is within this context that the conference on "The Freshman Year in Science and Engineering: Old Problems, New Perspectives for Research Universities" took place. The Alliance for Undergraduate Education and the universities it represents are committed to addressing seriously the issues of the science and engineering pipeline and of scientific literacy, as well as other important issues of undergraduate education, such as writing across the curriculum, assessment, and access for a diverse population.

The founding universities of the Alliance are 12 of the largest institutions of higher education in the United States. Their combined undergraduate student bodies total more than 300,000. If effective change is to take place in the way the nation educates its young people, that change will begin with universities such as those represented by the Alliance.

The present conference is not, of course, the first effort to address the issues of science education. The National Science Foundation's 1989 Directorate in Science and Engineering Education Directory of Awards lists almost 500 pages of innovative teaching projects by faculties around the country. It has been suggested, however, that the science and engineering faculty at research universities are "not yet on the playing field." This conference is an initiative to enter the game in a forceful way.

The conference focused on the introductory courses in science and engineering, the "freshman year," because it is in these courses that universities have both the greatest opportunity of attracting young people into science and the greatest danger of repelling them from science. Presentations ranged from discussions of a highly successful program to improve performance of minority students (and others) in mathematics at the University of California at Berkeley, to the introduction of "Mildred," a "great-great-great grandmother" brassica rapa plant cultivated by Professor Paul Williams, director of the Center for Biology Education at the University of Wisconsin–Madison, who uses plant experiments to interest both college and K-12 school students in the concepts of biology.

Although the conference included separate sessions in mathematics, chemistry, biology, engineering, and physics, the consistency of the major concerns expressed by participants was striking. These problems include a fixed view of what should be in the introductory courses, an ignorance among faculty about what is taught in other disciplines, a lack of knowledge about the students and how they are assimilating what they are being taught, an "undesigned redundancy" in the educa-

tional system that forces students to learn some introductory points over and over again in a succession of science programs, a feeling of boredom among both faculty and students, and a profound lack of curiosity about science on the part of most students.

Of the new perspectives that emerged from the conference, two are perhaps the most significant. The first is that the faculty at research universities must assume major responsibility for the state of science and engineering education in the United States, and must also accept responsibility for its improvement. The second is that in the process of change, the faculty must change their attitude toward and approach to teaching, rather than expecting today's students to adapt themselves to old methods. This requires that the faculty know their students better than they do now. It requires new strategies for active involvement in learning and for increasing access to women and minorities. This second point immediately stimulates worries about quality and standards among many university faculty. This is not the point; excellence is not being sacrificed. The effectiveness of old patterns of teaching and expectations about students are being questioned, however. These and other points will be elaborated upon in the remainder of this report.

Rather than record the detailed discussions that took place at the conference, we explain here the broad areas of consensus which emerged as a result of those discussions. The editorial "we" will be used throughout the report, not in the sense of unanimity, but in the sense of a broad consensus among the participants at the meeting. The consensus statements are supported by extensive quotations of participants' remarks. We apologize to the many participants whose contributions helped make the conference a success, but whose specific comments are not recorded in this report.

We hope that the consensus that emerged from the conference will be a helpful guide in the effort to revitalize science education in this nation and, more specifically, in the nation's major research universities. Much of it applies to comprehensive universities and to liberal arts colleges. In particular, the criticisms of the content and methods of introductory science and mathematics courses apply broadly throughout higher education.

Research universities have both unique resources in undergraduate education and unique problems in realizing the full potential of these resources. Undergraduates at research universities have a vast number of options to pursue in science and engineering and the opportunity to share the excitement of research at the forefront of knowledge. Yet all too often, the undergraduates are only vaguely aware of these opportunities, and the faculty fail to share the vibrancy of their professional lives with the undergraduates. The proceedings of this conference show that there is growing energy among the faculty of research universities for addressing these problems and bringing about fundamental change.

Science education is such an important national problem that research universities must give it high priority.

Science research faculty have major responsibility for change in the nation's attitudes toward and competence in science, engineering, and mathematics. This includes not only change at the university level, but also change in K-12 education, in the training of teachers, and in outreach and science literacy. The problem of scientific literacy is as important as, and is tightly coupled to, the "pipeline problem." Research faculty are important role models for their students, many of whom go on to become teachers at all levels of the educational system, and for the general public, including school children.

Bassam Shakhashiri, assistant director of the Directorate for Science and Engineering Education of the National Science Foundation, suggested in his keynote address that "for the nation to maintain its international prominence, we need to have a steady supply of scientists and engineers coming through the pipeline," but Shakhashiri also warned that "what is at stake is not only the quality of life in the United States but the quality of life on the planet."

When one looks at the problem in that way, it becomes apparent that the basic question facing university faculty is a philosophical one: What does it mean to be a professional in the twenty-first century? The term "professional" has become in some ways demeaned in our culture, referring as it does to anyone who takes pride in his or her craft. But, in the classic sense, a professional is one who takes responsibility for the maintenance and standards of the profession. We in academia must own the problem of the pipeline and of scientific literacy. If we don't to take steps to solve it, who will?

We cannot just limit ourselves to making incremental improvements in classes at our own universities. We must reach out to those in the elementary schools and high schools who teach science, to those in the mass media who influence the public, and to those in private industry who, with us, have an occupational stake in the development of qualified scientists and engineers.

Faculty at research universities must make a searching evaluation of the balance in their professional lives between research and undergraduate teaching. It is not a question of "either/or"; it is a question of balance. As James Duderstadt, nuclear engineer and president of The University of Michigan told the conference participants: "It is time that we as science faculty gave far more attention to what we teach, whom we teach, and how we teach."

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II. THE CENTRAL PLACE OF STUDENTS

Research universities are in an excellent position to teach the "best and brightest" who are already motivated to pursue careers in science. These are the students typical of the 1960s, and faculty at research universities have a special mission to retain them in science. They also have a special mission to reach out to those well-prepared entering students who for whatever reason do not plan to pursue science majors, as well as to the general student without a good preparation who needs a grounding in science in order to lead a productive life in our democracy.

These students cannot be taught in the style of the 1960s, however. Professor Lillian McDermott, a physicist at the University of Washington, argued that the problem is not that the subject matter taught is incorrect. The problem is that faculty members often don't realize that what their students are learning is different from what the faculty are teaching. (See Appendix I for a detailed discussion of this point.)

"Most instructors think of students as mirror images of themselves. The point is that very few people in the classes we teach are like ourselves. That doesn't mean that they are not smart. It is just that their emphasis and their interest and their drive and their maturity may not be the same as ours. It is very common for physics professors to get carried away and to assume that their fascination with the subject is shared by the students."

Denice Denton, assistant professor of electrical and computer engineering at the University of Wisconsin-Madison and Presidential Young Investigator, graphically described the influence of changing family structures:

"My mother was a single parent trying to raise three children. I didn't eat mathematics for breakfast. I ate pop tarts while watching Gilligan's Island. I'm a prototype for the people you are teaching."

When she attended the Massachusetts Institute of Technology, that background caused her problems. "In my sophomore year, I took a signals and systems course at MIT. I found it sort of interesting, but I kept wondering what I was doing in it. I failed to see the utility. That's because I had no knowledge base. I managed to go 17 years without knowing the numbers on a radio dial were frequencies; no one ever mentioned that to me."

Several speakers also warned that an academic mind-set that developed in an era of increasing enrollments, when the faculty could concentrate on the most motivated and committed students, may in today's culture serve to discourage the very students, particularly women and minority students, that universities are attempting to recruit for science majors.

University science faculty in the United States are no longer in a position to choose arrogantly among the best and brightest of the nation's students who are already motivated to pursue scientific careers. Professor Sidney Perkowitz, Candler Professor of Physics at Emory University, said faculties must ask themselves if "we really want our students to succeed?" He questioned the common admonition some faculty make on the first day of class: " 'Look to your right; look to your left. At the end of the semester, one of you won't be here.' Such faculty take pride in the fact that some won't succeed. Why do we do that?"

Professor Denton recalled receiving a form letter from an MIT professor who suggested she consider a field other than engineering because she had done poorly on a single examination in a sophomore course. That kind of cavalier attitude toward students in introductory courses creates massive leaks in the scientific pipeline, Professor Denton asserted.

Professor Uri Treisman, director of the Dana Center for Innovation in Mathematics and Science Education at the University of California, Berkeley, argued that "the courses we're teaching were designed at a time of student surplus in the 1960s and 1970s. The courses evolved to control the flow of students into the classroom. We always think it will be 1968 again and that we will have lots of students. But, now, we have a situation where almost no one wants to be a mathematician or a chemist or a physicist." (See Appendix II for a further discussion of Treisman's research.)

In years past, university attitudes that discouraged women and minorities from pursuing careers in science and engineering may have had ethical and moral implications in that the nation was missing the

Science education should accommodate itself to the students and not vice versa.

productivity and insight of men and women who had much to offer. As a practical matter, however, the lecture halls and laboratories of the educational institutions in the 1960s remained filled, and neither government nor industry had major difficulties in finding researchers to fill available jobs.

Today, if women and minorities do not choose to become researchers and technologists, the nation will suffer not only ethically but materially. Dean Karl Pister, of the College of Engineering at the University of California, Berkeley, told conference participants that "we have got to get beyond the idea that women and minorities are educationally disadvantaged. That's not the problem at all." The problem, Pister continued, is not that women and minorities have inadequate preparation in science but that most students today enter college inadequately prepared. What makes the education of women and minorities so important is that they constitute an increasing proportion of the student body and the eventual work force. If education is to serve the students, then education must understand that women and ethnic minorities make up a substantial part of the student body and will do so in the future (Pister noted that 42 percent of students in California's K-12 system are ethnic minorities).

Minority students show strong interest in careers in science and engineering when queried at a high school level, Professor Treisman said. "Minority students disproportionately want to be science students. They come to the university and, in 10 weeks, their aspirations are buried." He suggested that failure in introductory science courses at the university level also tends to quell the thirst for learning of incoming minority students in all areas—and, perhaps, that of their siblings at home.

"We began to see the enormous consequence to lots of people of failure in these introductory science courses. Kids who were put on a pedestal and who worked as hard as they could, who dreamed of becoming science people" had their aspirations buried in classes that didn't serve their needs.

Professor Judith Franz, of the Department of Physics at West Virginia University, noted that the differences between men and women in the classroom may be more differences of self-image than of inherent ability. Women, she said, tend to blame themselves if they do poorly on tests; men tend to blame the test. What that difference in perception can lead to all too often is that women who do poorly on initial tests doubt their ability as potential scientists and leave the field.

If science wishes to recruit and retain women students, Franz continued, senior faculty will have to find ways to communicate with them, to encourage them. "Take your women students very seriously," she said. "If you treat them as professionals, they will see themselves as professionals. Give them encouragement. Show them that you respect women students."

The process doesn't involve coddling women, Professor Franz continued. But, in a discipline in which there are 4,500 male physics teachers and 100 female teachers, many of the unspoken assumptions about the advantages of a career in physics are geared toward men.

She said she believes the joys of a career in science include a satisfaction that comes from solving problems, of gaining insights into how things work, of "being considered bright," of being part of a group of "smart people with a commitment to learning," of being part of a "great tradition," and of identifying with senior faculty members.

But women, as minority members of groups of male scientists, tend to ask themselves questions like "Am I good enough?" and "Do I really want to compete?" They need encouragement to answer these questions with a "yes," Professor Franz asserted.

III. COMMUNICATING INNOVATIONS IN SCIENCE EDUCATION

The communication infrastructure that is so effective in research is not highly developed in teaching and outreach. There is a growing energy among research faculty to become involved in science education, and individual commitment is a prerequisite for systemic change. But the individual efforts need to be communicated and built upon.

The concern of the Alliance is that teaching projects, many of them notable successes, remain isolated efforts. They are isolated too often within the universities that sponsored them, and they are isolated too often within fields of study. A project that develops important concepts about the teaching of mathematics may have equal application to the teaching of chemistry—but chemistry faculties may never learn of it. These successes too often remain isolated incidents.

The results of innovations in teaching need to be communicated not only within the university, but to the general public. "We communicate science to ourselves very well," agreed Bassam Shakhashiri. "But we don't communicate science to the rest of the population."

"Everyone who is a scientist gets up in the morning anticipating the excitement of what's coming," suggested Professor Williams. "If we can develop an informational system that shapes that excitement as deeply into society as possible, we will reap the rewards and benefits of the enthusiasm from a lot children, teachers, and parents." This enthusiasm can be translated into more science majors, a more scientifically literate public, and stronger public support for research.

Professor Williams also noted that "every experience in teaching is an experiment in itself," a concept to remember as one studies the possibilities of improving the way science is taught.

There are notable successes and tremendous promise in the undergraduate and outreach programs at research universities, but the successes need to be communicated and moved from the "pilot plant" to the "full production" mode.

The walls of the university should come down in order to broaden access and to draw upon the resources of the K-12 system, industry, and the public.

Professor Naomi Fisher, of the University of Illinois at Chicago, noted that "to a great extent, the majors in mathematics are made at the pre-college level. What can happen in college is that students can be dissuaded from their decision. But it is unlikely under present conditions that you can take a student who has not already started on that path and somehow suddenly give him or her this wonderful, exciting charge to go into mathematics. So we are dependent on what happens at the pre-college level to create the population from which we will get future mathematicians and people working in mathematically related fields. Not only are we dependent on the pre-college level, but we also have a great impact on what happens at the pre-college level especially through teaching math to future elementary and high school teachers."

The walls between scientists and members of the general public must come down. Bradley Moore, dean of the College of Chemistry at the University of California, Berkeley, suggests that education of the public must be a first priority if science wishes to maintain the support it needs. Public concern, both legitimate and misinformed, has greatly limited research into applications of technology, and public concern threatens to handicap basic research as well, he warned.

"As a chemist, when I look at the state of public attitudes toward chemistry, I am concerned. Toxic waste has become a synonym for chemistry. The regulatory environment for industry and research reflects more paranoia than fact and logic or sensible evaluation of risk."

The public does have reason for concern, Moore continued. It can look at the toxic waste dump at Love Canal or read about the hazards of the "ozone hole" caused by released gases on earth and see evidence for concern. What is needed, however, is an educated public, one that can differentiate between those areas where serious changes must be made to protect the environment and public health and those areas where there is no real risk.

"Obviously, we have to educate science and engineering majors. But to educate these people in a society that doesn't appreciate or support their activities is really not going to be productive. Most of our universities don't do a good job of educating our own students who are not scientists or engineers. We need to be concerned about science teachers, K-12 teachers, whom we rely on to supply us with intelligent, well-trained students."

V. THE IMPORTANCE OF COLLABORATION AMONG THE DISCIPLINES

The sciences today share common enemies: curricula that no longer engage the students or the faculty, a student body that has lost its ability to be curious, faculty who have become disenchanted with teaching large lecture sections. These problems cut across the disciplines, and their solutions will be applicable across the disciplines as well.

One advantage of any conference of this type is that it introduces interesting people to each other. The demands on faculty time are such that eminent scholars in chemistry can work a few buildings, or even a few floors, away from eminent scholars in physics or in astronomy, and yet never learn what each is doing.

Dean Pister said, "I cannot remember a single occasion at Berkeley at which there was an intentional effort made to engage engineers, chemists, physicists, and mathematicians to evaluate and redesign a freshman year course."

The walls must come down. The student who fails to choose a career in botany is not more likely to choose a career in chemistry. He or she is more likely to choose a career outside the sciences altogether. Students are typically interested in problems of modern society, and these problems often have multifaceted scientific and technological components. Discipline-specific introductory courses are well suited for already committed majors, but they are not able to tap the richness available in a full discussion of issues dealing with the environment, health, or technological innovation.

The inevitable conclusion is that several doorways into science need to be built, and the one for the majority of students will require the contributions of engineers, mathematicians, and physical and biological scientists. Other disciplines will also be needed. If better teaching methods are needed, university schools of education must have some insights in that process. Academic psychologists have learned much about motivating young people. The schools of communication have spent decades learning the skills of marketing that can now be tapped to develop ways of interesting youth in science.

The walls between the disciplines should come down to enhance collaboration on the curriculum.

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Important questions should be asked and answered at the departmental level: What is important to know? What can be left out of introductory courses? What incentives do the faculty want to reward exemplary results in teaching?

"People have a fixed view of what is in the introductory courses," says Professor Nelson Markley, chairman of the Department of Mathematics at the University of Maryland. "We are insular—and, I suspect, it's not just in mathematics."

Dean Pister spoke of an "undesigned redundancy" in the educational system that forces students to learn some introductory points over and over in a succession of science programs yet does not expose those students to the excitement of the sciences. "The motivation of students is at great risk in the present system of class organization," he said.

Dean Moore argued that many universities are going in the wrong direction in regard to their freshman students, providing them with laboratories that are "old, dirty, unsafe, and certainly unacceptable by any industrial standard." Still other universities "have faced up to the problems of the freshman chemistry lab and have canceled it. I really think that's a very long step in the wrong direction."

Participants in the conference also agreed that the balance between undergraduate teaching and graduate and faculty research remains a concern of education. Dean Pister noted that "the pervasiveness of the pressure to do research has eroded support for undergraduate teaching programs. Research universities share a common mission, the discovery and dissemination of knowledge through teaching, research and public service. While this mission hasn't changed in the last century, the relative importance of faculty time devoted to the fulfillment of each part of this mission has changed. The prestige and rewards and support for both the institution and the individual have changed, and there has been an inevitable change in academic faculty life."

This means that the energy for innovations in introductory courses often is not present in research-oriented departments. Since the faculty at the departmental level have primary responsibility for the balance in their professional lives, a prerequisite for generating the necessary energy and commitment is a thorough examination of what is really important for the health of their profession.

No longer can faculty claim that the policies of university administrators seem to encourage only research. President Duderstadt stated: "Perhaps it is time that science departments move away from the perspective of their role as a talent filter, designed to separate out only the most talented and motivated students, and develop an entirely different perspective by actually encouraging students to pursue the sciences. Perhaps deans, chairs, faculty, and particularly students should be asking hard questions, not simply about the research reputation of a department, but beyond that about its record in student recruitment, defection, and persistence rates. Perhaps we need a fundamental change in attitude. Why not aim at enabling the largest possible number of students to succeed in introductory courses rather than focusing on separating budding Nobel laureates from the herd?" (A complete copy of President Duderstadt's remarks is in Appendix III.)

VII. THE ROLE OF JUNIOR FACULTY

The tenure system is an effective socialization process; a young faculty member who has been told for six years to put innovations in teaching near the bottom of the professional agenda cannot be expected to value it highly after tenure is achieved. There is much energy and creativity among young faculty, postdoctoral fellows and graduate students for innovation in teaching and for public outreach, but it often does not survive the tenure process.

Professor Denton was the only invited speaker at the conference on the Freshman Year in Science and Engineering who has not already attained tenure. "There's one thing that you all have that I don't have, and that is tenure," she noted. "Everyone in this room has alluded to the fact that, at research universities, only research counts. Teaching and service are not only irrelevant but discouraged for the most part."

She suggested that junior faculty can add greatly to the interest of new students. "We come with enthusiasm for teaching—but you do a good job of thwarting it with your tenure system. Junior people are smart and will do whatever you people tell us you want. If you emphasize teaching, we'll do it better. If you generate us in your image or in this image that you've said is the best image, to do only research, we're not going to change after we get tenure."

That is certainly not to say that research is not a top priority for junior faculty at research universities nor that teaching freshmen should be a task relegated only to junior faculty. It is a task for the academy as a whole. But it is also true that the academic system is a system of values, and the values it reflects will be those of the people at the top and—in faculty circles—the people at the top are those who grant tenure. If tenure is based on research, and teaching is given only lip service in the process, then teaching will not be a high priority among younger faculty, many of whom have a natural bent for teaching and chose academic careers, in part, because of their love of teaching.

But, as Professor Neal explained, "There is an unfortunate belief among many faculty that their colleagues who desire to teach the large introductory courses are either extraordinarily committed to teaching or are unable to do much else. Moreover, the argument goes, if they are in the former category, they will soon be in the latter. In a setting where research-related items are at the top of everyone's list, it will be only infrequently that some teaching-related items—which, incidentally, may rank number two on everyone's list—will be taken care of. It is precisely for this reason that strong leadership from university administrations is required. Somehow, departments have to be shown that it is in their best interest to pay careful attention to instructional matters."

Young faculty should be included in the process of change.

The health of scientific research over the next several decades depends upon strong leadership in science and engineering education at the federal level, especially within the National Science Foundation.

There is inevitable tension between teaching and research at our nation's research universities, and the balance between these two vital activities needs to be adjusted. University faculty typically look to the NSF for support of basic research, and they are not reticent in demanding increased funding of research. A principal mission of the NSF, however, is also to support education, since it is not possible to sustain a viable research base without strong educational programs at all levels. Thus, the NSF has an essential leadership role to play in helping our universities examine their role in science and engineering education.

In the final analysis, the question of improving science and engineering education is a question of priorities set at many levels. If the nation is to have a scientifically literate population and be assured of an excellent scientific workforce, a national consensus must be built from the elementary schools through university science and engineering departments. Support for change must develop in university administrations, state legislatures, and the public. All that is true.

It is also true that all those efforts will have little impact if the improvement of science and engineering education is not a priority of the federal government. The federal government has exerted tremendous influence in building the research agenda and infrastructure of our research universities. It must now use its influence to nurture a readjustment in the balance between teaching and research.

The National Science Foundation, the Department of Education, the Department of Defense, and the Departments of Agriculture, Commerce, and Labor all have a role to play in determining the future of science education. But the central role should be played by the NSF because of its record of working effectively with university faculty in building the nation's scientific infrastructure.

We commend the NSF for establishing the Division of Undergraduate Mathematics, Science and Engineering Education within the Science and Engineering Education Directorate, and we support the Congress and the executive branch in their initiatives to increase funding. We are disappointed, however, by the signal that has been sent to the science community by the postponement of the initiative in introductory science curriculum development. We urge that the initiative be fully funded. We are distressed by the early problems that have been encountered in implementing the laboratory equipment program for the universities. We strongly support this program and hope that the problems will be resolved quickly.

There is a remarkable precedent for increased federal investment in science education. The national effort launched after Sputnik created three decades of almost mind-boggling advances in science, all made possible by a steady flow of young men—and, again, a few young women—into the classrooms and laboratories of the nation's colleges and universities and then into the laboratories and factories of American industry.

Today, we do not have the challenge of a Sputnik to galvanize public support for science and engineering education, and the economic challenge from Europe and the Pacific Rim has not yet provided a compelling alternative. The nation needs effective and visionary voices for excellent science and engineering education within the context of excellent basic research. The NSF is the natural forum for these voices.

IX. THE ROLE OF THE ALLIANCE FOR UNDERGRADUATE EDUCATION

The conference participants were enthusiastic about the opportunity to meet with colleagues from other research universities to share experiences. There was also a strong desire to stop talking and to take action to improve science and engineering education. Suggestions of the conference participants for how the Alliance can help in this process include setting up communication and information networks among the disciplines; promoting collaborative working groups on curriculum, teaching methods, and other principles of education; encouraging science faculty, education faculty, and K-12 interaction; establishing a Commission on the Freshman Year in Science and Engineering Education, to report in three years; establishing a speaker/workshop corps as a resource for universities; and giving visibility to exemplary teaching.

Except as noted briefly in Finding VIII above, this report has spent little time looking at what "others" should do to improve science education. Those of us who dedicate our lives to teaching bear the ultimate responsibility for rescuing that profession and building its standards.

"The question I have for you to think about very seriously is a question of readiness," Bassam Shakhashiri challenged the conference during his keynote address. "Are you prepared to take on the responsibility of attending to the problems of undergraduate science education, of pre-college mathematics education? Is the academy ready to take on that responsibility? Do we have the beginnings of a coherent national plan to bring about fundamental changes in the way we train scientists at the undergraduate level, in the ways we recruit talent at the pre-collegiate level?"

Shakhashiri argued that "the problem, as I see it, is not one of financial resources. The problem as I see it is one of intellectual development in the custodians of knowledge in science, in mathematics, to show up on the playing field to do what must be done."

President Duderstadt agreed. "Our challenge for the decade ahead is to take the steps necessary to build a new knowledge-based society which will be competitive in a world marketplace. I believe we can meet this challenge. But it is also clear that to do so will require will and sacrifice by us all. It will require renewed commitment to that most fundamental of all characteristics in the new economic order: quality. And it will take renewed investment in that most critical resource for our future: our system of public education."

The Alliance for Undergraduate Education should create a strong science and engineering focus.

APPENDIX I.
Student Understanding in Physics: What We Teach and What Is Learned

Professor Lillian C. McDermott
Department of Physics
University of Washington

Professor Lillian McDermott is Professor of Physics at the University of Washington, with a special interest in how students learn physics. Her workshop described a research project to determine the relationship between what physics instructors teach and what students in their classes actually learn.

Professor McDermott described a research project conducted by the Physics Education Group at the University of Washington. An important objective is to determine the relationship between what physics instructors teach and what students in their classes actually learn. She noted that all teachers hope that they are teaching in a way that will help students understand major principles in the discipline. "What we are trying to do is to subject to scholarly inquiry what it is the students learn. We are trying to do that the way you would try to find facts in any other area."

What the researchers do is to interview students in some depth about their understanding of concepts encountered in the study of various topics in introductory physics. During an interview, a student is shown a simple demonstration and asked to make a prediction about what will happen if a specified change is made in the system. The student must explain the reasoning used to make the prediction in terms of the relevant physical concepts.

"Everyone who teaches physics thinks that being able to make connections to the real world is important. Many instructors assume that while students are studying the formalism of physics they are also learning how to make these connections. There is considerable evidence, however, that this is not the case. Our group is especially interested in examining how well students are able to relate concepts and principles to observations of actual objects and events."

Professor McDermott used an example from geometrical optics to illustrate how a typical investigation is carried out. In one research task, the demonstration consisted of a clear brightly lit bulb, a converging lens, and a screen, all mounted one after the other so that an inverted image of the bulb filament appeared on the screen. The student was asked to predict what would happen if the lens were removed. Interviews were conducted with 80 volunteers enrolled in introductory physics, most of whom would receive a grade of A or B in the course. Before studying geometrical optics, fewer than half were able to answer the question correctly. Of those students who had completed the relevant material in the physics course, only about half could correctly predict that without the lens there would be no image.

"A common error made by many of the students was to claim that if the lens were removed the image would be right side up. From the results obtained on this task and several others, it appeared that many of the students thought that light from an object comes in a straight line to the screen, where it forms an image, with or without a lens. These students failed to recognize the necessity of the lens for forming an image. For them, the purpose of the lens was to invert the image."

Apparently the students had failed to understand a very basic concept and had developed a serious misconception instead. "No professor ever told them the function of a lens was to invert the image. This is something they taught themselves, regardless of what they were being taught by the professor."

The students participating in this study who had been taught the relevant material could apply the thin lens formula to solve standard numerical problems. However, results from the performance of the students on several interview tasks indicated that they did not have a meaningful understanding of the basic principles expressed by the formula. They did not seem to recognize that the location of the object determines a unique location for the image nor that light from each object point is focused by the lens to a single image point (approximately). An instructor who was grading problems on a short-answer quiz might determine that the students had learned the subject matter when, in fact, they had not really understood the underlying concepts at all.

The investigation described is only one of several that have produced similar results. This situation leads to some obvious questions for science instructors. "One question that physicists must address is 'How should we spend our time in the introductory physics course?' Should we be sure that students have been presented with many concepts so that those who have taken the course and may not take another physics course have at least been exposed to the ideas (maybe correctly, maybe incorrectly), or should we place our emphasis on helping students achieve a sound understanding of basic concepts and on helping them develop ability in scientific reasoning? We cannot even begin to answer this question without some knowledge of what students are actually learning."

One of the characteristics of science instruction at the university level is the faculty's perception of the student. "Most instructors think of students as mirror images of themselves. They believe that students think the way they do. The point is that very few people in the classes we teach are like ourselves. That doesn't mean that they are not smart. It is just that their emphasis and their interest and their drive and their maturity may not be the same as ours. It is very common for physics professors to get carried away and to assume that their fascination with the subject is shared by the students."

The need to look at what happens to students during instruction was emphasized. It was pointed out that the type of formal investigation described is only one of the ways in which we can gain insight into how students think. Another is through informal research that you can do as an instructor. By asking qualitative questions and insisting on explanations, you can learn a great deal more about student difficulties than by asking questions that students can answer by routine application of algorithms. "When students come for individual help during office hours, you should try to listen rather than talk. It is much more effective not to answer student questions directly but to ask questions to guide them to find their own answers. Only if you listen to students can you find out what is puzzling them."

"There is an inevitable consequence to incorporating the suggestions that have been made into the way we teach. If we teach for understanding, we've got to go more slowly."

APPENDIX II.
Improving Academic Performance in Mathematics

Professor Uri Treisman
Dana Center for Innovation in Mathematics and Science Education
University of California, Berkeley

Professor Uri Treisman is also Eugene Lange Professor Mathematics Education and Social Change at Swarthmore College. His workshop dealt with programs developed at Berkeley to help minority students succeed. Although the work at Berkeley was pioneering, Treisman noted that there are other notable programs, particularly that at the University of Texas at Austin. The following is an excerpt from his workshop.

Historically, the work at Berkeley started from some investigations trying to understand why the black students were doing so dismally. There were very strongly held views about the nature of the problem and these views turned out to be wrong. There was deep institutional belief that the problems were not within our control, that there was really only a small handful of students who did well at math, and that small differences in motivation would matter in competitive classes. There were beliefs about family backgrounds that were very interesting because none of us had ever met the families. There was the great liberal dream that it has nothing to do with ethnicity at all and that the problem is really income.

Later our ideas changed. Motivation wasn't the factor, nor was family income. The kids from the inner city had paid a very heavy price to get where they were. The kids from the suburbs were almost indistinguishable in their ideas about education from the white kids. Academic preparation—we really have overwhelming data now from lots of places that the strongest blacks have the most difficulty. The kids who come in as the strongest do very poorly. The students we have are not the products of school systems; they are the products of families that have organized themselves for success. The families of kids who were successful were public school teachers, civil service workers, military and postal workers. There was a negative correlation with money.

What we found is that the blue collar whites and the farm kids were getting massacred. They didn't have a clue as to what was going on. When we looked at the blacks, we found the principal problem was they were leading two separate lives. They had a study life and a personal life and they really didn't intermix them. So, the blacks would do our course exactly like in high school. They confused the course with going to college. They would do their homework religiously. They would spend six to eight hours a week on homework. They'd prepare for tests and they'd get Cs,Ds, and Fs.

We contrasted these students with the Cantonese students who would put in 14 hours a week outside of class. They would work 8 to 10 hours alone and then they would get together—they would usually make a meal—and then they would sit down and work together.

The black students were only connected to college through the courses. If something went wrong, they were out-of-there quickly, or they would change to economics or one of the social sciences.

We decided never to just do things for minorities only. That would be a purely political act. We decided that the principal problem was to break down this isolation, to build an undergraduate student life. We were impressed by the fact that we didn't know what the good students did. But, what was nice, there was a rich enough setting that it didn't matter too much what they did. So, we made an adjunct section, roughly half minority, in which the students worked 6, 8, 10 hours a week extra on challenging math [not remediation; students hate remediation]. The idea was to make it non-political, recruit the students into an honors section, figure out empirically what you had to do to help the students excel.

These programs have to be laboratories to improve instruction for everyone. The minority students are becoming the majority, so we can't design programs that are just remedial programs for isolated groups of 24 students.

The special programs don't work for everyone, but at Berkeley they seem to help about two-thirds of the students involved. They work best when designed for freshmen. Freshman instruction is so abysmal that it wasn't hard, with 8 or 10 extra hours a week, to help the minority students do better than class average and to do at least a full grade, sometimes two full grades, better than the average of the blacks.

The thing that became obsolete about our minority program was that it wasn't connected to departmental instruction and, as minority population grew, it became impossible to support this. In 1987, we made an abrupt change. Rather than having these adjunct sections, the idea was to have some of the big lectures taught in strengthened versions with earlier exams, harder exams, more homework. In the discussion sections, the idea was to intensify instruction. We recruited a dozen minority students—the sections had 24 students—about 12 minorities and about 6 white and Asian kids and we left 6 slots open for students in the lectures as a whole.

The students don't compete with each other. The regular sections determine the curve—so all the students in the special sections can get As. The idea is that the students come into the section and they are going to do richer work. There is unabashed advocacy for mathematics. They know we are going to try to recruit them as math majors. In some of the sections, there are two-week projects. Students give four hours a month of public service to mathematics (usually, that means they adopt a high school).

These students hang out together after school, even if they are commuters. They put in as many as 100 extra hours over their normal study. If possible, they take a minimum full-time load. The idea is to make their first year intensive, mastery oriented, even if they have fewer classes. We want them to get As. They can't build on four Cs.

There is a cost. The graduate student works with one section, rather than two and, even so, their work is a little harder. But graduate students compete for the sections.

We don't run the program just for minorities, but it is an affirmative action program. We are favoring the minorities and we are favoring the blue collar and rural whites. But a quarter of the slots are open to students by competition, so all students have a chance to qualify. We know that mixing the students and interconnection is essential.

In recruiting students for the programs, it is important to recruit from strength. Don't recruit students for "remedial" programs. Recruit them for what is perceived as an honors program. The minority students who enroll in a major research university are, generally, exceptional students and see themselves that way.

APPENDIX III.
America at the Crossroads: The Challenge of Science Education

James J. Duderstadt

Introduction

The subject you have asked me to talk about this evening, science education, has been very much on my mind these days. Like many of you, I have shared the growing public concern about the overall quality of education in our country. For example, last week in a special supplement to the Sunday edition of the *New York Times* entitled "Science Under Scrutiny," a number of alarming facts were noted:

1. In international comparisons, the United States high school seniors ranked fourteenth among fourteen nations in science achievement.

2. College science enrollments have declined by more than a factor of two over the last two decades.

3. Of those who enter college intending to major in science, 40 percent drop out after their first course and more than 60 percent drop out before graduating with a degree in science.

4. Foreign nationals now comprise 60 percent of engineering and mathematics doctorates and over 50 percent of physical science doctorates.

In recent years I have been formally involved in these matters as a member of the National Science Board. In fact I currently serve as a member of the NSB standing committee on Education and Human Resources. I also served on a special subcommittee a few years ago chaired by one of our colleagues, Professor Homer Neal, which was charged with evaluating the state of undergraduate science education in the United States. Our findings, which were made public in what is referred to as the Neal Report, concluded that there was overwhelming evidence that undergraduate education in science, mathematics, and engineering was simply not fulfilling its mission. To quote the report:

> Serious problems, especially problems of quality, have developed during the past decade in the infrastructure of college-level education in the United States in mathematics, engineering, and the sciences. A deterioration of college science, mathematics, and engineering education is a grave, long-term national threat.

My concerns about the quality of science education in America also relate directly to a number of the themes of change I have suggested to the University in recent months:

1. The changing nature of our population as we become ever more diverse and pluralistic;

2. The changing nature of our ties to other nations and other peoples, as the United States becomes a world nation; and

3. The changing nature of our social, cultural, economic, and intellectual activities as we evolve from a resource and labor-intensive society to a knowledge-intensive society.

I have suggested that these changes would demand change as well in the institutions that serve our society—including, in particular, our university. I have even suggested that we should view the 1990s as a time to meet the challenge and the opportunity to re-invent the university, to design a university of the twenty-first century. In fact, I am convinced that if we do not try to shape our own destiny in the years to come, it will be shaped for us by external forces and interests.

Of course, I am not claiming to have the answers about what it will mean to re-invent the university. Quite the contrary! What I have to offer are rather some questions, observations, and speculations about the issues of renewal and revitalization in our teaching, research, and service missions. In this way I hope to trigger a dialogue across our campus over the coming year that will engage us all in thinking and discussing the future and our place in it.

On some occasions later this year I plan to say more about these matters, including our relations with other societal institutions; the changing nature of undergraduate education; the role of the liberal arts; and our fundamental missions of research, graduate and professional education, and service. This evening I intend to raise some questions about intellectual renewal of undergraduate education. Here I will focus my remarks on a number of issues relating to the manner in which we approach science education, both as preparation for a career in the basic or applied sciences, as well as from the perspective of science as a critical component of liberal learning necessary for life in the twenty-first century.

The Age of Knowledge

Let me begin, however, by first reading some of the handwriting on the wall, by commenting briefly on the rapidly changing world in which we live and the kind of future for which we must prepare. Looking back over history, one can identify certain abrupt changes—discontinuities in the nature, the very fabric of our civilization: the Renaissance, the Age of Discovery, the Industrial Revolution. There are many who contend that our society is once again undergoing such a dramatic shift in fundamental perspective and structure.

Today we are evolving rapidly into a new post-industrial, knowledge-based society, just as over a century ago, our agrarian society evolved through the Industrial Revolution. We are experiencing a transition in which intellectual capital, i.e., brain power, is replacing financial and physical capital as the key to our strength, prosperity, and social well-being. As Erich Bloch, Director of the National Science Foundation, puts it, we have entered a new age, an "age of knowledge in a global economy." And in this age the major forces behind economic and social change are science and technology themselves.

Of course, we know that technology has been transforming our society at an ever accelerating rate. We are living in a time in which the application of knowledge through technology is pervasive in all human affairs. Indeed, technological innovation, achieved by applying new knowledge created through basic research, has been responsible for the dominant part of all U.S. productivity gains since the Second World War. It is clear that the technologies of transportation and communication have made possible the integrated world economy which now characterizes our society. Tremendous new industries have been created by new knowledge. Electronics is the obvious example of the past several decades and perhaps biotechnology will be the example in the years ahead. These and other new industries all depend on knowledge—and the people who create and apply it—as their most critical resource.

But of course, knowledge is highly mobile; it is not tied to geographical regions nor to political structures. The knowledge revolution today is happening world wide, and it is happening very rapidly. The intimate relationship between technological evolution and economic development is widely understood in all developed nations. As more countries understand that knowledge is now the critical resource for economic prosperity, more are making serious investments in their science and technology base. In this sense then, our nation is being challenged in the knowledge business not only by Europe and Asia, but increasingly by Latin America and Africa as well. We no longer have a corner on the market. The field is leveling out.

The Challenge of Change

But beyond the changing economic order, today we are also entering a period of great intellectual change and ferment. New ideas and concepts are exploding forth at ever-increasing rates. We have seen that each advance can call into question fundamental premises. Think about the recent instances in which a new concept has blown apart our traditional views of the field. For example, in my own field of physics, the nineteenth century view of our world gave way to Einstein's theory of relativity and quantum mechanics. Our understanding of the molecular foundations of life is changing dramatically the very nature of the biomedical sciences. Examples abound today of striking new discoveries triggering potential revolutions of similar magnitude in the nature of our scientific knowledge. Disciplinary boundaries are crumbling. Technology is extending the reach of science to the edge of the universe and the beginning of time.

It is clear that if we are to harness the power of this knowledge explosion for the good of man, the capacity for intellectual change and renewal will be of critical importance to our institutions and to us as individuals. As the pace of creating new knowledge accelerates, we are entering a period in which permanence and stability are less important than flexibility and creativity. This is a period in which the only certainty will be the presence of continual change. And the ability to relish, stimulate, and manage change will be one of the most important skills we can give our students.

In some ways, so much change and instability is daunting. But we should take heart, because as Alfred North Whitehead said, "The great ages are unstable ages."

Clouds on the Horizon

The Pipeline Problem

The unprecedented explosion of knowledge we are experiencing means that we will be relying increasingly on a well-educated and trained work force to maintain our competitive position in the world, our standard of living at home, and our social stability. Previous economic transformations in America, such as the introduction of modern agriculture and the industrial revolution, were associated with major public investment in infrastructure such as railroads or electrical networks or highways. Today the equivalent infrastructure will be an educated population. It seems clear that education will be the pivotal factor in determining the direction of the economic transition in this country and its effect on our citizens.

Yet here we face very serious difficulties ahead because we are simply not educating enough new people to keep our economy competitive. Further, there are serious signs that the education of the present American workforce is simply inadequate to meet the demands of the next century. This challenge has become known as the "pipeline problem" since it involves the full spectrum of education, from preschool through K-12, through higher education, through graduate and professional education, to lifelong education and science literacy.

K-12 Education: A Nation at Risk

Last December I attended a conference of the top scientists, government officials, and corporate leaders from around the world. At this meeting, a senior executive of Nissan reported that, after an extended visit to the United States, a number of senior Japanese officials were asked to assess America's greatest strengths and weaknesses. The group unanimously responded that America's greatest strength was its system of higher education, particularly our research universities. Our greatest weakness was considered to be our system of primary and secondary public education.

By any measure, K-12 education is in serious trouble. We are indeed "a nation at risk." Our educational system simply has not responded to the challenges of the age of knowledge. In the face of a veritable explosion of knowledge, it is clear that both the knowledge and skills of the graduates of our primary and secondary education systems continue to deteriorate. At every level of education American children rank near the bottom in their knowledge and skill levels in science and mathematics when compared to peers in other advanced nations.

By any reasonable standard, it is clear that we are in serious trouble. For example, in tests of composition ability, only 20 percent of high school seniors were able to write an adequate letter. Only 12 percent of these students could reorder a group of six fractions by size. Astonishingly, only 5 percent of high school graduates were entering college ready to begin college-level science and mathematics courses. These and many other measures demonstrate quite forcibly that only 15 to 20 percent of our children are reaching an intellectual level that will enable them to function in the everyday world, and only 5 percent will be capable of further education in science at the college level without remedial instruction.

The Aging of America

As the Japanese businessmen noted, the "good news" is that our colleges and universities continue to be the envy of the world. But here, too, we face major challenges.

Of particular concern are projected demographic trends. The dominant factor controlling the supply of scientists and engineers is the size of the college age population. As we slide down the backside of the post-war baby boom, the number of students of college age is declining rapidly.

From 1976 through the mid-1990s, a 20 percent to 25 percent decline in the number of high school graduates is expected. Assuming that the fraction of these graduates choosing to enter science and engineering stays the same, and assuming constant demand for scientists and engineers (both very conservative assumptions), the National Science Foundation now estimates that there will be a cumulative shortfall of almost 700,000 scientists and engineers by the turn of the century. To put it another way, just to compensate for the demographic decline, the fraction of students choosing science and engineering majors will have to increase by over 40 percent to maintain even the present number of graduates.

A Nation of Minorities

But the composition of the college age population is also changing, even as it declines in magnitude. In 1966, 44 percent of college freshmen were women. Today the number is 52 percent. In addition, by the turn of the century, roughly one-third of college age students will be people of color. If present trends continue, by the year 2020, 30 percent of college age students will be African Americans and Hispanic Americans, students who have not traditionally had the encouragement or the opportunity to pursue science and engineering careers.

The most striking recognition is that during the 1990s, almost 90 percent of the new people entering our labor force will be women, minorities, and immigrants. This means that the fastest growing pool of young adults is comprised of minorities who have traditionally had the lowest participation rate in college, the highest drop-out rate in high school, and the least likelihood of studying science and mathematics. In fact, although blacks and Hispanics presently account for 20 percent of our population, they account for less than 2 percent of our scientists and engineers. Women account for only 15 percent of scientists and engineers. It seems that at all the key decision points during a student's career, from K-12 to undergraduate to graduate and professional schools, minorities and women fall away from the science, mathematics, and engineering pipeline at a steeper rate than the rest of our population.

Declining Student Interest

There is yet another factor that intensifies concerns about the nation's supply of educated scientists and engineers, and this has to do with the dramatic decline in student interest in science majors. For a number of years Kenneth Green and his colleagues at UCLA have been performing longitudinal studies of freshman interest in undergraduate majors. These studies reveal that the overall proportion of freshmen planning on majoring in mathematics and science has dropped from 11.5 percent to 5.8 percent over the past twenty years. The proportional change by field is particularly striking:

Mathematics:	4.6% —> 0.6%
Physical Sciences:	3.3% —> 1.5%
Biological Sciences*:	3.7% —> 3.7%
Engineering:	12% —> 8.6%
Computer Science:	8.8% —> 2.7%

* (although over two-thirds of these are pre-med majors)

In sharp contrast to the dismal losses in the sciences, Green found that student interest in undergraduate business majors has now increased from 10.5 percent to 23.6 percent.

These studies also revealed that the earlier patterns that saw prospective secondary school science and mathematics teachers pursuing undergraduate majors in these disciplines have essentially disappeared. Very few aspiring science and mathematics majors plan careers as high school teachers.

Green's alarming data are augmented by additional studies indicating that over one-half of those freshmen selecting science majors either change their minds during entry-level courses, drop out at a later point, or reluctantly complete their programs rather than "waste" investments of time, energy, and money. Students increasingly view entry-level courses in science as either inaccessible or unrewarding. It seems clear that many freshmen who have come to science well prepared and expecting to major in science disappear after the freshman year due to their performance or frustration with entry-level courses.

Recent studies at the University of Michigan exhibit similar trends. If we track the number of upper class concentrators in science majors over the last twenty years, we find the following changes (1969 to 1989):

Mathematics:	281 —> 160
Physics:	97 —> 61
Geology:	31 —> 13
Biology:	essentially stable but with 65 percent indicating pre-med majors

Further, a recent survey conducted by the Women in Science Program found that of 420 seniors graduating in 1987, 35 percent of women and 24 percent of men initially interested in science later decided against it due to problems with entry-level courses. Of these, 85 percent reported that they had taken courses which had discouraged them from continuing the study of science. Even among those who remained in the major, 65 percent reported that their entry-level courses had seriously discouraged them.

Science Literacy

In our world today we are witnessing an unprecedented explosion of knowledge. Indeed, in some fields the doubling time for new knowledge is roughly five years. In some rapidly evolving engineering fields, in fact, graduates find their knowledge almost obsolete by the time they finish their degree program.

And yet, in the face of such an extraordinary growth in knowledge, public ignorance is truly extraordinary. A recent NSF survey indicated that only 18 percent of those asked said that they knew how a telephone works, and when questioned, only 9 percent gave the right answer. Yet, more than 50 percent of

those surveyed indicated that they believed that we were being visited by aliens from outer space. In another survey, it was found that only 3 percent of high school graduates could pass a simple test on science literacy. Further 12 percent of college graduates and only 18 percent of Ph.D.'s could pass this test!

Of comparable concern is the fact that many people, including many highly educated people, are not only ignorant of science but are actually hostile to it. In a sense, we are rapidly becoming a nation of illiterates in science and technology, no longer able to comprehend, control, nor cope with the technology that is governing our lives.

The De-emphasis of Science Instruction in Undergraduate Education

Those of us in universities have to accept some responsibility for this frightening situation. Through our undergraduate curriculum, we prepare our graduates to cope with a world of scientific and technological change, compensating in part for the deficiencies of our K-12 education system. Yet, today in American universities we have ceased insisting on a balanced education for our students. We have failed to provide them with the foundation necessary to cope successfully with the increasing pace of scientific and technical change. Amazingly, most colleges require only two or three semesters of courses in science and mathematics for non-science majors, and these are generally watered down courses at that.

It wasn't always this way. In 1850, almost 150 years ago, Harvard required all of its undergraduates to take 25 percent of their curriculum in mathematics and science, including physics, zoology, chemistry, and biology. Indeed, the Harvard curriculum included a course in science or mathematics in every semester of study. By contrast, today for non-science majors, Harvard requires only two one-semester courses—one in the physical sciences and one in the natural sciences. Stanford similarly requires only three one-quarter courses—one in science, one in mathematics, and one in computers (which is essentially a word processing course).

Conclusions

It seems clear that if we look at the combined effects of demographics with student preferences and educational trends in our universities, we have a time bomb on our hands. We are not only educating too few scientists and engineers to sustain the strength and prosperity of our nation, but we are producing a generation of Americans who are scientifically illiterate. These students will suffer from a life-long estrangement from the very knowledge that will govern their lives in the years ahead.

Time is running out. It seems clear that we have two major and urgent challenges to address:

1. We must move immediately to plug up the leaks in the education pipeline so that more students manage to make it through the gauntlet posed by majors in science and mathematics.

2. Over the longer term, it is clear that we must reform the education system—that is, completely rebuild the pipeline—to respond to the changing world in which we live.

In our colleges and universities it is time that we as science faculty gave far more attention to what we teach, whom we teach, and how we teach.

Some Observations and Questions

Entry-Level Science and Mathematics Instruction

As we have noted, there is an alarming loss of students in the early college years due to difficult courses, bad teaching, and declining interest. Indeed, 40 percent of those entering college intending to major in science drop out after entry-level courses. Fully 60 percent will drop out before completing a major. In fact, we see in science courses and science curricula, perhaps the ultimate example of the modern university's focus on the selection rather than the development of human talent; we focus on "weeding out" rather than "adding value." Every year thousands of academically talented and highly motivated students enroll in college with the intent of majoring in science—and then drop out.

A recent survey by the University of Michigan Women in Science program identified several of the key reasons for this attrition: (1) the poor quality of teaching in introductory courses; (2) the overall classroom attitude; (3) the impact of stereotypical attitudes towards women and minorities among professors, TAs, and fellow students; and (4) the lack of role models in introductory science instruction. But the problems are far deeper than this, being tightly intertwined with the corporate culture of science education which has arisen in research-based departments for the past several decades.

In many universities science departments have developed an almost perverse attitude of taking pride in the number of students who flunk out of introductory science courses. Perhaps this was inevitable in view of the heavy service teaching obligation of most science faculty. Departments of chemistry, physics, and mathematics were assigned not only the responsibility for the science content of general education requirements, but also the specialized science instruction of other disciplines, such as engineering and medicine.

Whatever the reason, the difficulty of introductory courses in chemistry and physics has been legendary. In fact, organic chemistry is generally regarded as not simply a career-shaping, but in fact, a career-stopping experience for a great many pre-med students. At times there seems to be an almost informal competition to see which science classes can achieve the lowest grades or lowest mean GPAs, which can eliminate the most students from the field.

Instead of focusing on selectivity in this way, perhaps we should question instead the viability of any program that loses one-half or more of its potential clients. This is particularly alarming in the face of the fact that the sciences generally tend to attract a disproportionate number of academically able and motivated students. Kenneth Green observes that "if undergraduate science departments were run like for-profit businesses—that is, without substantial institutional subsidy—most programs would be bankrupt, largely because of their capacity (some say, basic inclination) to alienate potential clients."

Perhaps it is time that science departments move away from the perspective of their role as a "talent filter" designed to separate out only the most talented and motivated students, and instead develop an entirely different perspective by actually encouraging students to pursue the sciences. Perhaps deans, chairs, faculty, and particularly students should be asking hard questions, not simply about the research reputation of a department, but about its record in

student recruitment, defection, and persistence rates. Perhaps we need a fundamental change in attitude. Why not aim to enable the largest possible number of students to succeed in introductory science courses rather than focusing on separating budding Nobel laureates from the herd?

The Quality of Science Teaching

The fact that more than 50 percent of entering freshmen intending to major in the sciences fail to complete the B.S. program in these fields is a major problem. It is compounded by the number of future teachers, lawyers, politicians, and citizens who are rendered permanently allergic to these fields by unfortunate encounters with introductory courses. Surveys indicate that the majority of students find that introductory level courses, whether geared to majors or to students satisfying general education requirements, fail to educate them about the subject, let alone stimulate and involve them. Students report that the courses are largely irrelevant to their lives and the effort required far exceeds the benefit reaped. Perhaps their view is short-sighted. But there is no arguing with the fact that entry-level courses are not encouraging and enabling large numbers of students to continue further study and careers in science.

There are other more fundamental problems. The higher levels of intellectual abstraction required by modern science have led to an intensification of the introductory curriculum. All too frequently courses demand that students master abstractions before they have developed adequate experience and understanding of the phenomena characterized by the abstractions. Further, introductory science instruction rarely takes into account the differences in intellectual and emotional maturation of students. Instead, all students are forced to move at the same pace and follow the same method.

The Science Major

The high attrition observed among prospective undergraduate science majors suggests that it may be time to re-think our basic concept of the undergraduate major. Science majors are typically structured as narrow, rigidly sequenced, and intensively hierarchical programs with little flexibility.

Ironically, this narrow approach to science education contrasts sharply with the strong intellectual pressures that are connecting the classical disciplines—mathematics, physics, chemistry, and biology—with the applied sciences, engineering and medicine. However, in sharp contrast with the overlapping intellectual nature of modern research, science instruction continues to suffer from hardening of the disciplinary arteries with ever-increasing specialization, excessive abstraction divorced from context, and a distinct state of disciplinary inertia. Our present department structure itself, characterized by limited communication and coordination and strong possessiveness for students, continues to move away from the interdependent nature of the sciences.

Science as a Component of the Liberal Arts

It is clear that mathematics and science instruction has largely disappeared from the general requirements of the undergraduate curriculum. Perhaps this was inevitable during a century of intellectual fragmentation in the academy, a century during which humanist and scientific cultures drifted further apart.

Yet one cannot deny the importance of the natural sciences to a liberal education. Like the arts, the humanities, and the social sciences, the natural sciences are an expression of our human culture. To be ignorant or alienated from the sciences is to lose touch with a part of ourselves and our civilization. Especially when science and technology so dominate our lives, how can we afford to leave its development and application to a few "experts"? It seems to me imperative that we begin to redesign the liberal arts curriculum to once again include a very substantial mathematics and science component, if we want to provide a liberal education appropriate for the twenty-first century. There must be an integration, not of the arts and the sciences, but rather the arts with the sciences.

Some General Recommendations

Each generation must face the challenge of determining for itself and for its age what the core of a liberal education should be. In most colleges today there is little faculty consensus about the purposes or appropriate content of an undergraduate education, either in general or in the sciences. An important first step is to bring together the science faculty with their colleagues in the humanities and social sciences to determine the role of the sciences in a liberal education.

I believe both students and faculty have a common interest in trying to reconceptualize and revitalize entry-level science courses and core sequences. There is a real irony here, since most scientists truly enjoy teaching. Yet, as a result of the present reward structure, few are fortunate enough to be able to devote a significant portion of their time, energy, and creativity to teaching. There is simply not the time nor the opportunity for the innovation and creativity that is the key to learning. We need to ask how we can redesign entry-level courses to enlarge the window of access into the sciences. Can this be accomplished by rewarding our most talented faculty for creative teaching and by rethinking methods, structures, and content?

One of the key problems in introductory science is our continued dependence upon the lecture format. This is probably the least effective way to facilitate learning in the sciences. Studies show that scientific understanding develops best when students become active partners in learning, when they are encouraged to see science in its human context, and when they can refine their interpretations through collaboration with peers and mentors.

It also is essential that the very best faculty be brought into the design and teaching of entry level courses in an effort to convince more students to pursue majors in the sciences. Here I have a particular axe to grind with the customary practice of assigning introductory courses to new faculty members. It would seem that since new faculty are most up-to-date with research practices in their narrow field of interest, they would be most appropriately assigned first to teach advanced graduate seminars. Then, as their teaching skills mature and their perspective broadens, they could be assigned to lower level courses. Only the most distinguished and capable faculty should be assigned the challenge—and the

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privilege—of teaching the most introductory science courses, so key in nurturing the interests of prospective science majors.

I believe that some major pedagogical changes are necessary. We should rely far more heavily on learning through doing, on understanding the underlying principles and methods of science, and on using hands-on experiences rather than simply encouraging our students to accumulate facts and passively accept the opinion of others. We might also make far more use of novel teaching techniques, such as the use of "peer" teaching assistants (that is, outstanding undergraduates who have recently completed the same course sequence). Furthermore, we have barely begun to exploit the possibilities of new instructional technology in facilitating both teaching effectiveness and learning capacity.

The tightly sequenced majors now characterizing most science disciplines should have more flexibility to allow students the opportunity to both interrelate and perhaps even shift among science majors as their interests change. At the same time, I am convinced we must reduce tensions in the science majors, which are simply too intense and do not allow adequate opportunity for a liberal education. The undergraduate curriculum should be viewed as a network of roads with many points of entry and many points of crossover.

Students should be able to exercise many more options to broaden their academic programs and shift to other majors. Since the curriculum of most science majors is already seriously overburdened, the exponential increase of new knowledge and skills can only be incorporated by reforming existing content, not by making majors even more intense. But, of course, here we run into a major challenge within the academy because of strong faculty resistance to removing or changing course content, no matter how obsolete or irrelevant.

Both the explosion and the evolution of scientific knowledge demand a life-time commitment to formal learning if professionals are to stay current. This should be built into the redesign of the undergraduate curriculum. At the recent Sigma Xi Conference on Science Education at Wingspread, the participants concluded that "the fundamental goals of undergraduate science education for all students should be the development of a knowledge base and intellectual skills that enable them to engage in lifelong science learning and to be able to apply their scientific knowledge to personal, professional, and civil endeavors."

More Specific Recommendations

A Science "Liberal Arts" Major

Perhaps as science faculty we need to take a broader view of the science major itself and cease assuming that every student majoring in our field intends to become a professional scientist. After all, most history majors do not intend to become historians; most philosophy majors do not intend to become philosophers. But we assume that all physics majors will become physicists, all chemistry majors will become chemists, and so forth. Hence we design highly specialized and intensive majors with this in mind.

What about a physics or a chemistry or a mathematics major for students intending to continue their studies in other professions such as business, law, teaching, or politics? Indeed, it seems that a liberal education with a strong concentration in the sciences would be an excellent preparation for the age of knowledge which will characterize our society in the years ahead.

Let me be quite clear here that I do not have in mind a watered-down science major—e.g., "physics for poets." Rather, I am suggesting rigorous science majors of a somewhat broader and more interrelated nature. Perhaps in these majors one would defer consideration of the most up-to-date and highly specialized research materials in favor of a broader perspective of the discipline. But rigor and depth would be comparable to that of the "career track" major.

Major/Minor Curriculum Options

In years past it was common to encourage or even require students to pursue intensive studies in both "major" and "minor" areas. For example, the physics major might have a minor in English literature, or the English major might have a minor in astronomy. Perhaps we should once again encourage our best undergraduates to pursue two majors—or at least a major and a minor—in widely separated fields of study. People capable of bridging scientific cultures and social and humanistic fields and concerns will be valued leaders in our future.

The Science Content of the Liberal Arts Curriculum

We are doing great disservice to our undergraduates and to society by allowing them to leave the university scientifically illiterate. The fact is that the natural sciences are a critical part of the liberal arts education demanded by our age. Unfortunately, few of our graduates leave our institutions today with a truly liberal education. Indeed, many of our faculty have not had the opportunity to benefit from a liberal education from this broader perspective.

A century ago it was felt that at least 25 percent of the undergraduate curriculum of a liberal education should consist of science and mathematics. Is it not appropriate to question whether, in this age that is increasingly dominated by science and technology, a similar content is needed by our students today? In fact, one might note that if "technical" institutions such as MIT and Caltech demand that their science students take at least 25 percent of their studies in liberal arts, perhaps liberal arts colleges should require that humanists invest 20 to 25 percent of their studies in the sciences, at least leading them up a gentle slope to higher levels of scientific understanding.

Transition Majors

Our present approach to science education is essentially a filtering process, a highly critical and hierarchical sequence of courses which pile, one upon another, thereby making it very difficult for students to change directions as their interests or abilities mature. Of course the party line is that science instruction must, of necessity, be highly vertical in nature. Unlike literature or social science—which are more extensive than intensive in nature—we maintain that the highly vertical subjects of science are difficult to learn after college. Hence, we suggest to students that unless they learn the language of science and mathematics early, they are likely to find science inaccessible later in their education or professional lives.

But recent studies of learning suggest that as students acquire more intellectual maturity, the learning process assumes more of a parallel, non-linear nature. True learning consists of mastering a subject simultaneously from a variety of perspectives, rather than proceeding in a sequential fashion to higher and higher levels of understanding.

Hence, perhaps we should rethink how to build programs of science instruction for students of greater intellectual maturity, even if their particular background is in sharply differing areas such as humanities or social sciences. Perhaps it is possible to design an educational program—although perhaps using non-traditional instructional methods—at the upper class or graduate level that would allow students with degrees in social sciences or humanities to make the transition into further graduate studies and careers in science.

Lifelong Education

Perhaps we should simply conclude that our conventional perspective of science education as a four-year undergraduate major—or even as an eight to ten year graduate program—is obsolete in a world in which the growth of knowledge increases at exponential rates. The explosive increase of scientific knowledge and the uncertainty about what knowledge will be required to comprehend future issues make it impossible for any student to acquire the knowledge in an undergraduate education necessary for a lifetime. Instead, might we not be better off by considering science education as a lifetime commitment to formal learning and use the undergraduate experience to prepare our students for this future? Then, if we begin with the assumption that our students would continue to study throughout their professional careers, we could redesign our undergraduate programs to make them far less specialized and far more suited to a world of change.

America at the Crossroads

Today our nation faces serious challenges that will clearly determine its future prosperity and well-being: the challenge of pluralism, the challenge of participation in a global community, the challenge of the age of knowledge, and the challenge of change itself. As we approach a new century, America is undergoing a profound and difficult transition to a new economic and social order. Our prosperous industrial economy, an economy that allowed us to build the world's great institutions, including some of its finest universities, is rapidly disappearing. Our challenge for the decade ahead is to take the steps necessary to build a new knowledge-based society which will be competitive in a world marketplace.

Let there be no mistake about it. This will not be an easy transition. The outcome is still very much in doubt.

It is clear that the ties between the quality of life in this country and the educational skills of our people are strong. It is also clear, unfortunately, that unless there is a revolution in the way we promote learning, the nation's economic standards will follow those of the test scores of our students.

In my frequent interactions with leaders of the public and private sector throughout this nation, I detect an increasing sense of pessimism about our nation's will and capacity to take the actions necessary to prepare for this future. There is an increasing sense that American industry can no longer depend on domestic knowledge resources, that is, upon a well-educated labor force or an adequate supply of scientists, engineers, and other professionals. This arises because of three factors:

1. There is increasing pessimism that the staggering problems facing K-12 education can be overcome on the timescale necessary to preserve our economic strength.

2. Further, despite the fact that most other nations regard higher education as America's greatest strength, there is little sign that this view is shared either by our elected political leaders or the public at large. Indeed, it has become fashionable to attack our universities, even as we continue to seriously underfund them.

3. "Transnational" companies seek resources, whether they be labor, processes, or knowledge, wherever they can get them—highest quality and lowest price. The rapid growth of these companies suggests that outsourcing of knowledge to other parts of the world will become increasingly common as the quality of American education deteriorates.

This is truly a frightening prospect. Industry has already outsourced labor and manufacturing. Can our nation afford to lose its competitive capacity to produce and apply knowledge as well?

We simply must face the facts. We are not going to be prosperous if all we do is mow one another's lawns — or worse yet, arrange leveraged-buyouts of each other's companies financed by junk bonds. We have to bring something to the table of the international marketplace. We have to generate our wealth through our people, through their knowledge and their skills.

I, for one at least, do not share the pessimism of many of my colleagues. I believe we can meet the challenge of the knowledge-based and global society that is our future. But it is also clear that to do so will require will and sacrifice by us all. It will require renewed commitment to that most fundamental of all characteristics in the new economic order, quality. And it will take renewed investment in that most critical resource for our future, our system of public education.

APPENDIX IV.
The State of Science and Mathematics Education in the United States

Brief Summaries of Thirteen Reports Appearing Between 1983 and 1989

Prepared in the Office of the Assistant Director for Science and Engineering Education, National Science Foundation October 20, 1989

EXPLANATORY NOTE: *For some years, there has been a steady stream of reports dealing with the state of all or part of the science and mathematics education enterprise in the United States. By now they number in the hundreds, but only a few attract attention that is sustained. While it may be timely and seem efficient to concentrate one's attention on the most recent issuances in the stream, to do so risks the establishment of a view without a context.*

In this longer-than-anyone-wanted-or-expected-it-to-be document there are collected semi-analytical summaries of a select few of such reports. The examples chosen are of three kinds: Policy-Oriented Studies, Studies of Student Achievement, and Blueprints for Curriculum Reform. All have had or will have lasting influence.

CONTENTS

Part I. Policy-Oriented Studies

A NATION AT RISK, April 1983
Report of The National Commission on Excellence in Education (created by Secretary of Education T. H. Bell in August 1981).

EDUCATING AMERICANS FOR THE 21ST CENTURY, September 1983
Report of The National Science Board Commission on Pre-college Education in Mathematics, Science and Technology created by the Board in 1982).

TURNING POINTS, June 1989
Report of the Task Force on Education of Young Adolescents, Carnegie Council on Adolescent Development.

OPPORTUNITIES FOR STRATEGIC INVESTMENT IN K-12 SCIENCE EDUCATION, May 1987
Options for the National Science Foundation; A report by the staff of SRI International.

TOMORROW, October 1984
Report of the Task Force for the Study of Chemistry Education in the United States; American Chemical Society.

TO SECURE OUR FUTURE, March 1989
The Federal Role in Education. Report of the National Center on Education and the Economy.

Part II. Studies of Student Achievement

THE SCIENCE REPORT CARD, September 1988
Report of Science Achievement in the 1986 National Assessment of Educational Progress.

THE MATHEMATICS REPORT CARD, June 1988
Report of Mathematics Achievement in the 1986 National Assessment of Educational Progress.

A WORLD OF DIFFERENCES, January 1989
Report of an International Assessment of Mathematics and Science.

SCIENCE ACHIEVEMENT IN SEVENTEEN COUNTRIES, 1988
Report of preliminary results from a 1985-86, multination study by the International Association for the Evaluation of Educational Achievement.

Part III. Blueprints for Curriculum Reform

SCIENCE FOR ALL AMERICANS (PROJECT 2061), 1989
Report of the first of three phases of a decade-long K-12 science curriculum reform project undertaken by the American Association for the Advancement of Science (AAAS).

CURRICULUM AND EVALUATION STANDARDS FOR SCHOOL MATHEMATICS, March 1989
Report of the Working Groups of the Commission on Standards for School Mathematics of the National Council of Teachers of Mathematics (NCTM).

EVERYBODY COUNTS, 1989
A Report to the Nation on the Future of Mathematics Education—by the Mathematical Sciences Education Board (MSEB), Board on Mathematical Sciences (BMS), and Committee on the Mathematical Sciences in the Year 2000, of the National Research Council (NRC).

A Nation at Risk
April 1983

Report of The National Commission on Excellence in Education (created by Secretary of Education T. H. Bell in August 1981).

Charged to: Assess the quality of teaching and learning in US public and private schools, colleges and universities; compare American schools and colleges with those of other advanced nations; study the relationship between college admissions requirements and student achievement in high school; identify educational programs which result in notable student success in college; assess the degree to which major social and educational changes in the last quarter century have affected student achievement; and define problems which must be faced and overcome "if we are successfully to pursue the course of excellence in education."

Findings for science and mathematics: Only 31 percent of graduates complete intermediate algebra, 6 percent (introductory) calculus; in many other industrialized nations, courses in mathematics (beyond arithmetic), biology, chemistry, physics, and geography start in grade 6 and are required of all students—the time spent (class hours) on these subjects is about three times that spent by even the most science-oriented US students; 35 states require only 1 year of mathematics, and 36 require only 1 year of science for a diploma; too few experienced teachers and scholars are involved in writing textbooks; the shortage of teachers in mathematics and science is particulary severe; half of the newly employed mathematics (and) science teachers are not qualified to teach those subjects.

Recommendations:

A. CONTENT: " . . . that high school graduation requirements be strengthened and that at a minimum, all students seeking a diploma be required [to take] the following curriculum during their 4 years of high school: . . . (b) 3 years of mathematics; (c) 3 years of science; . . . and (e) one-half year of computer science."

B. STANDARDS AND EXPECTATIONS: " . . . that schools, colleges, and universities adopt more rigorous and measurable standards, and higher expectations, for academic performance and student conduct, and that 4-year colleges and universities raise their requirements for admission."

C. TIME: ". . . that significantly more time be devoted to learning (more effective use of the existing school day, a longer school day, or a lengthened school year) . . ."

D. TEACHING: (1) High educational standards for those preparing to teach; (2) salaries [that are increased,] . . . professionally competitive, market-sensitive, and performance-based; (3) an 11-month contract; (4) career ladders; (5) substantial (employment of) nonschool personnel resources to help [meet] the shortage of mathematics and science teachers; (6) incentives to attract outstanding students to the teaching profession; and (7) involvement of master teachers in designing teacher preparation programs and in supervising teachers during their probationary years.

E. LEADERSHIP AND FISCAL SUPPORT: " . . . that citizens across the Nation hold educators and elected officials responsible for providing the leadership necessary to achieve these reforms, and that citizens provide the fiscal support and stability required to bring about the reforms we propose."

Educating Americans for the 21st Century
September 1983

Report of The National Science Board Commission on Pre-college Education in Mathematics, Science and Technology (created by the Board in 1982).

Charged to: " . . . define a national agenda for improving elementary and secondary education in mathematics, science, and technology, . . . including an action plan defining the appropriate roles for federal, state, and local governments, professional and scientific societies, and the private sector in dealing with currently perceived problems in precollege education."

Findings: "By 1995, the Nation must provide, for all its youth, a level of mathematics, science and technology education that is the finest in the world." " . . . sweeping and drastic change (are required): in the breadth of student participation, in our methods and quality of teaching, in the preparation and motivation of our children, in the content of our courses, and in our standards of achievement. We propose to initiate this difficult change through a strategy of (1) building a strong and lasting national commitment to quality mathematics, science and technology education for all students; (2) providing earlier and increased exposure to these fields; (3) providing a system for measuring student achievement and participation; (4) retraining current teachers, retaining excellent teachers and attracting new teachers of the highest quality and the strongest commitment; (5) improving the quality and usefulness of the courses that are taught; (6) establishing exemplary programs—landmarks of excellence—in every community to foster a new standard of academic excellence; (7) utilizing all available resources, including the new information technologies and informal education; and (8) establishing a procedure to determine the costs of required improvements and how to pay for them.

Recommendations:

LEADERSHIP: "The President should immediately appoint a National Education Council, reporting directly to him, to identify national educational goals, to recommend and monitor the plan of action, to ensure that participation and progress are measured, and to report regularly to the American people on the standards and achievements of their schools." ($2.75M annually)

"The States should establish Governor's Councils to stimulate change, develop state educational goals, and monitor progress. Local school boards should

foster partnerships with business, government and academic to encourage, aid and support in solving the academic and financial problems of their schools.

"The Federal government should finance and maintain a national mechanism to measure student achievement and participation in a manner that allows national, state and local evaluation and comparison of educational progress." ($5M annually)

FOCUS ON ALL STUDENTS: "The nation should reaffirm its commitment to full opportunity and full achievement by all."

QUALITY TEACHING AND EARLIER AND INCREASED EXPOSURE: "Top priority must be placed on retraining, obtaining and retaining teachers of high quality, . . . and providing them with a work environment in which they can be effective. Top priority must be placed on providing earlier, increased and more effective instruction in mathematics, science and technology in grades K-6. Considerably more time should be devoted to mathematics, science and technology throughout the elementary and secondary grades."

MODELS FOR CHANGE: "The Federal Government should encourage and finance, in part, the establishment of exemplary programs in mathematics, science and technology in every community, which would serve as examples and catalysts for upgrading all schools." (For 1000 secondary and 1000 elementary schools, initially, $276M annually.) "The Department of Education and the National Science Foundation should support and facilitate the dissemination of information to help build this network of exemplary programs."

"State governments should promote and local school districts should establish such programs as a major strategy toward upgrading schools."

SOLUTIONS TO THE TEACHING DILEMMA: "State governments should develop teacher training and retraining programs in cooperation with colleges and universities. The potential of science museums as sites for such programs should be encouraged and supported.

"It is a Federal responsibility to assure that . . . appropriate retraining is available. In-service and summer training programs should be established with Federal support." (For Federal initiatives, $349M annually.) "For the long term, teacher training by the States should continue as an ongoing process."

"Every State should establish at least one regional training and resource center where teachers can obtain supporting services such as computer instruction and software and curriculum evaluation.

"The National Science Foundation should provide seed money to develop training programs using the new information technologies." ($30M)

"States should adopt rigorous certification standards, but not standards which create artificial barriers to entry of qualified individuals into teaching.

"Elementary mathematics and science teachers should have a strong liberal arts background, college training in mathematics and the biological and physical sciences, a limited number of effective education courses, and practice teaching under a qualified teacher. Secondary school mathematics and science teachers should have a full major in college mathematics and science, a limited number of effective education courses, and practice teaching under a qualified teacher. Both elementary and secondary teachers should be computer literate. Teacher training should incorporate the use of calculators and computers in mathematics and science instruction.

"Liberal arts colleges and academic departments need to assume a much greater role in training elementary and secondary teachers. Basic education courses should be revised to incorporate current findings in the behavioral and social sciences.

"In the short run, the pool of those presently qualified and teaching must be enlarged. State and local school systems should draw upon the staffs of industry, universities, the military, and other government departments, and retired scientists to provide sources of qualified teaching assistance. Local systems should take actions to facilitate the entry and classroom training of such special teachers.

"School systems should explore means to adjust compensation in order to compete for and retain high quality teachers in fields like mathematics, science and technology. Compensation calculations must include consideration of intangible benefits such as the length of the work year, promotion potential, and similar factors.

"State and local governments should provide means for teachers to move up a salary and status ladder without leaving the classroom. Local school systems, military and other government entities, and the private sector should all explore ways to extend the employment year while providing supplementary income and revitalizing experience.

"Professional societies, school, States and the Nation should finds ways to recognize the performance and value of the excellent teacher."

"We must take action to make the classroom a place where teachers can teach and children can learn—an exciting place with more opportunity for student-teacher interaction. We must build a professional environment that will attract and hold talented and well trained teachers, despite the allure of the private sector. State and local governments should work to improve the teaching environment."

IMPROVING WHAT IS TAUGHT AND LEARNED: "Local school districts should revise their elementary school schedules to provide consistent and sustained attention to mathematics, science and technology: a minimum of 60 minutes per day of mathematics and 30 minutes per day of science in grades K-6; a full year of mathematics and science in grades 7 and 8.

"Every State should establish rigorous standards for high school graduation, and local school districts should provide rigorous standards for grade promotion. We should curtail the process of social promotion. All secondary school students should be required to take at least three years of mathematics and of science and technology, including one year of algebra and one semester of computer science. All secondary schools should offer advanced science and mathematics courses. This requirement should be in place by September 1, 1985.

"College and universities should phase in higher mathematics and science entrance requirements, including 4 years of high school mathematics, including a second year of algebra, coursework covering probability and statistics, 4 years of high school science, including physics and chemistry, and one semester of computer science.

"Specific school personnel should be obligated to inform students of these rigorous requirements. School districts and community colleges should

cooperate in assisting students whose preparation is inadequate to allow them to take the next steps in their education.

"The National Science Foundation should take a leadership role in promoting curriculum evaluation and development for mathematics, science and technology. It should work closely with classroom teachers, technical experts from business and government, school boards and educational researchers, as well as with professional societies. Representatives of publishers and higher education associations should become involved as the work proceeds, to encourage development and transfer of these ideas to actual material for the classroom." ($52M annually)

"The National Science Foundation should set up a process to evaluate existing curricula, identify good curricula, disseminate information, act as a clearinghouse and promote the development of guidelines for new curricula as necessary."

"The Federal Government should support research into the processes of teaching and learning at both the basic level and the level of classroom application." ($10.5M annually)

NEW INFORMATION TECHNOLOGIES: "The National Science Foundation should lead in evaluating progress in the application of new technologies, supporting prototype demonstrations, disseminating information, and supporting research on integration of educational technologies with the curriculum. These plans should not interfere with private initiatives now underway." ($36M annually)

"States should establish regional computer centers for teacher education and encourage the use of computers in the classroom for both teaching and administration. Top executives in the computer, communications, and information retrieval and transfer industries should develop plans which, in a good, economical, and quick way, enable school systems to use the technology. The national and state education councils and school boards should work with school districts and schools to develop plans for implementing these technologies in the classroom."

INFORMAL EDUCATION: "Youth organizations, museums, broadcasters and other agents of informal education should endeavor to make the environment for informal learning as rich as possible.

"Science broadcasts warrant continued and substantial Federal support as well as corporate and other private support." ($13M annually) "Federal regulation of commercial stations should include a required period of educational programming for children.

"The Federal government should provide supplementary support to encourage a rich spectrum of community and educational activities by science museums." ($25M annually) "Business and broadcasters should help to promote and publicize the efforts of institutions like science museums and public broadcasting. Local business groups and organizations with related interests should work with museums to supplement and encourage their activities and to create new programs to let children see science and technology in the real world."

Turning Points
June 1989

Report of the Task Force on Education of Young Adolescents, Carnegie Council on Adolescent Development.

A task force composed of distinguished persons from education, business, research, health, philanthropy, and government studied the situation and problems of the young adolescent in the United States today, particularly in relation to the role of the middle grades school. Most of the task force's findings and recommendations apply to science and mathematics education. The task force envisioned a 15-year-old well served in the middle years of schooling as being: "An intellectually reflective person; a person enroute to a lifetime of meaningful work; a good citizen; a caring and ethical individual; and, a healthy person."

Findings: Fateful Choices for Young Adolescents and the Nation

"By age 15, millions of American youth are at risk of reaching adulthood unable to meet adequately the requirements of the workplace, the commitments of relationships in families and with peers, and the responsibilities of participation in a multicultural society and of citizenship in a democracy. These young people often suffer from underdeveloped intellectual abilities, indifference to good health, and cynicism about the values that American society embodies."

"During early adolescence, many youth enter a period of trial and error . . . growth and development [are] more rapid than in any other phase of life except infancy." While they become biologically mature at earlier ages, many young adolescents remain intellectually and emotionally immature.

"Young adolescents increasingly look outward from the home to gain an understanding of themselves and their circumstances."

"The sense of community that once existed in urban neighborhoods and in some rural towns has eroded." "In these times of rapid change, when young people face unprecedented choices and pressures, adult guidance is all too often withdrawn."

"Surrounded only by their equally confused peers, too many [young people] make poor decisions with harmful or lethal consequences."

"During early adolescence, all youth are caught in a vortex of new risks." "Many problem behaviors of young adolescents appear to be interrelated." "The risks that all young people face are compounded for those who are poor, members of racial or ethnic minorities, or recent immigrants."

"It is estimated that the future of about 7 million youth — one in four adolescents — is in serious jeopardy." "Another 7 million may be at moderate risk . . . ." "But even among those at little or no risk of damaging behaviors, the pervasiveness of intellectual underdevelopment strikes at the heart of our nation's future prosperity. American 13-year-olds, for example, are now on average far behind their counterparts in other industrialized nations in mathematics and science achievement." "Most distressing is the fact that the critical reasoning skills of many American young adolescents are extremely deficient."

"Middle grade schools have been virtually ignored in discussions of educational reform in the past decade. Yet they are central not only to channeling

every young adolescent into the mainstream of life in American communities, but also to making vast improvements in academic and personal outcomes for all youth." "A volatile mismatch exists between the organization and curriculum of middle grade schools, and the intellectual, emotional, and interpersonal needs of young adolescents." "The ability of young adolescents to cope is often further jeopardized by a middle grade curriculum that assumes a need for an intellectual moratorium during early adolescence."

Recommendations: Transforming the Education of Young Adolescents

"The Task Force calls for middle grade schools that:

"Create small communities for learning where stable, close, mutually respectful relationships with adults and peers are considered fundamental for intellectual development and personal growth. The key elements of these communities are *school-within-schools* or houses, students and teachers grouped together as teams, and small group advisories that ensure that every student is known well by at least one adult.

"Teach a core academic program that results in students who are literate, including in the sciences, and who know how to think critically, lead a healthy life, behave ethically, and assume the responsibilities of citizenship in a pluralistic society. Youth service to promote values for citizenship is an essential part of the core academic program." ["The core middle grade curriculum can be organized around integrating themes that young people find relevant to their own lives." "In the transformed middle grade school, tests will more closely resemble real learning tasks."]

"Ensure success for all students through elimination of tracking by achievement level and promotion of cooperative learning, flexibility in arranging instructional time, and adequate resources (time, space, equipment, and materials) for teachers.

"Empower teachers and administrators to make decisions about the experiences of middle grade students through creative control by teachers over the instructional program linked to greater responsibilities for students' performance, governance committees that assist the principal in designing and coordinating school-wide programs, and autonomy and leadership within sub-schools or houses to create environments tailored to enhance the intellectual and emotional development of all youth.

"Staff middle schools with teachers who are expert at teaching young adolescents and who have been specially prepared for assignment to the middle grades.

"Improve academic performance through fostering the health and fitness of young adolescents, by providing a health coordinator in every middle grade school, access to health care and counseling services, and a health-promoting school environment.

"Reengage families in the education of young adolescents by giving families meaningful roles in school governance, communicating with families about the school program and student's progress, and offering families opportunities to support the learning process at home and at the school.

"Connect schools with communities, which together share responsibility for each middle grade student's success, through identifying service opportunities in the community, establishing partnerships and collaborations to ensure students' access to health and social services, and using community resources to enrich the instructional program and opportunities for constructive after-school activities."

A Plan for Action
Building a Future for Young Adolescents in America

"All sectors of the society must be mobilized to build a national consensus to make transformation of middle grade schools a reality"

"The Task Force calls upon the education sector to start changing middle grade schools now." "We urge superintendents and boards of education to give teachers and principals the authority to make essential changes, and work collaboratively to evaluate student outcomes effectively.

"We ask leaders in higher education to focus immediately on changes needed in the preparation of middle grade teachers and in ways of collaborating with middle schools to support their reform.

"We urge health educators and health care professionals to join with schools to ensure students' access to needed services and to the knowledge and skills that can prevent health-damaging behaviors.

"We call upon youth-serving and community organizations . . . to develop or strengthen their partnerships with middle grade schools.

"We call upon states to convene statewide task forces to review this report and systematically examine its implications for their communities and schools. We ask states to consider new mechanisms for providing the incentives that will be required to bring about local collaboration between schools and community agencies.

"We urge the President and other national leaders to study the recommendations of this report with a view to establishing a comprehensive federal policy for youth development, including funds for research and demonstration projects; support for pre- and in-service teacher education; full funding for successful existing programs for middle grade students . . . ; and, along with states and local school districts, relief from compliance with nonessential regulations that inhibit experimentation within individual schools willing to test the ideas contain in this report.

"We call upon the private and philanthropic sectors, including foundations, to continue to support new ideas and expand their efforts in the implementation of policies designed to render early adolescence a fruitful period for every young person. The Task Force recommends the establishment of a national forum, with regional equivalents, to monitor the development of new approaches and share information with those interested in transforming middle grade schools. We also recommend the creation of trusts, supported through private and public funds, to support experiments in middle grade innovations in state and communities.

"We call upon parents to become involved in defining goals, monitoring their children's studies, and evaluating the progress of the entire school. We urge parents to bring pressure for change in education, health care, and school-community partnerships. We urge parents, and other tax-payers, to support public schools and to demand from schools far better performance than schools now deliver."

Opportunities for Strategic Investment in K-12 Science Education May 1987

Options for the National Science Foundation; a report by the staff of SRI International.

Identification: In 1984, the Congress included in the appropriations bill for the National Science Foundation (NSF) a requirement for "a contract to develop a science education plan and management structure for the Foundation." As part of its response to this mandate, NSF awarded a contract to SRI International in March 1986 "to assess initiatives available to NSF to address problems and opportunities in science education."

Scope: The study was a broad examination of the role of the Foundation in efforts to improve K-12 science and mathematics education. It considered the range of opportunities available to NSF, and the Foundation's education goals, priorities, strategies, and options.

Findings: NSF Mission. "At the K-12 level, NSF can best serve the scientific and engineering enterprise, and the society as a whole, by promoting the development of a broad pool of competent and interested science learners through the age of 18."

To optimize its efforts in pursuit of this mission, NSF must "Identify targets of opportunity; Support core functions; and Invest strategically."

Opportunities: The report identifies ten opportunities for NSF "to guide the search for appropriate content and approach, improve professional capacities, and influence key institutions in the education infrastructure." They are:

1. To reconceptualize K-12 mathematics curricula and associated instructional approaches.
2. To rethink the approach to, and settings for, elementary science education; and, to reconceptualize the content of middle and high school science education.
3. To match science and mathematics education to diversity in the student population.
4. To bolster the support cadre serving mathematics and science teachers.
5. To help attract and prepare the next generation of well-qualified teachers.
6. To strengthen the informal science education community.
7. To improve and expand mathematics and science education publishing capabilities.
8. To improve science and mathematics testing and assessment.
9. To provide content-related professional leadership in state science and mathematics education reform.
10. To expand informal science learning resources and enhance their contribution to school programs.

Core functions: "As a base for strategic investment and as a resource to the science education community, NSF needs, on an ongoing basis, to: (1) promote effective professional interchange, (2) build the base of information and knowledge about science education, and (3) maintain support for innovation." "... (These core functions (are) the underpinnings for all improvement efforts."

Strategic investment. The report describes two "overarching strategies" that the Foundation could consider. [Neither of these is recommended specifically for the Foundation; rather, NSF is urged to adopt some definite strategy, which might be one of these two, a combination of them, or another equally definite alternative, "to guide the choice and implementation of initiatives so they are mutually supportive."]

An incremental improvement strategy "emphasizes upgrading current formal and informal educational systems, primarily through investments that achieve widespread impacts in the short term."

A fundamental change strategy "aims at exploring the possibilities, extending the state of the art, and searching for new approaches that can radically improve education over the long term.

The definitions of these contrasted strategies are fleshed-out by brief descriptions of four kinds of educational investments that might be made under each of them: Investments in improving content and approach; Investments aimed at strengthening professional resources; Investments aimed at systems upgrading; and Related core function investments.

The report then develops estimates for the two strategies of the resources necessary for full implementation of sets of initiatives of the four kinds. To avoid burdensome detail, and so as not to suggest year-to-year budget shifts, the estimates were presented for a five-year period.

Estimated Resources Over 5 Years	Strategy ($ in Millions)	
Kind of Investment	Incremental Improvement	Fundamental Change
Improving content and approach	$ 80-106M	$150-195M
Strengthening professional resources	$279-324M	$159-192M
Systems upgrading	$175-226M	$ 92-125M
Related core functions	$120-144M	$179-227M
Five-year Totals	$654-800M	$580-739M

Strategic Capacity. The study found that NSF's Directorate for Science and Engineering Education (SEE) "has evolved rapidly since its reinstatement (in 1983) and is developing a capacity for investing strategically in K-12 science education. The Education Directorate needs to continue that evolution with the full support of the Foundation as a whole." ... "NSF as a whole, not SEE alone, will need to exercise leadership in the scientific community on behalf of K-12 science education if it wishes to establish a more effective strategic presence in this area."

Tomorrow October 1984

Report of the Task Force for the Study of Chemistry Education in the United States, American Chemical Society.

Identification: A task force created by the American Chemical Society and comprising 23 chemical scientists from universities, colleges, schools, government, and industry, studied chemistry education in the United States during 1983-84. It considered the state and problems of chemistry education at every level from kindergarten through

postdoctoral. Most of the task force's findings and recommendations apply broadly to science and mathematics education, not just to chemistry.

Findings: "Misunderstanding of science is widespread and the public understanding of science is poor.

Too little science is taught in the elementary schools, possibly because too few teachers are well qualified to teach it. Neither programs to assist improvement of teacher qualifications nor good teaching are readily available.

Too few teachers of chemistry in high schools are well grounded in the subject; those that are are spread too thin, have too few mechanisms available for maintaining and improving their qualifications, and are too easily wooed away to more satisfying and more remunerative employment.

Laboratory exercises are slowly disappearing from general chemistry education in both high schools and colleges.

College chemistry for nonmajors has yet to find an appropriate character; that for majors is beset with unanswered questions about curriculum content, especially as it relates to future professional employment.

Applications of both information technology and discoveries about learning are occurring haphazardly.

Demand for—and supply of—well-educated chemists are poorly related to each other. Arbitrary barriers to entry and progress in the profession continue to be reported.

Industry does much to aid science education, but should do much more."

Recommendations: "The highest priority recommendations of the Task Force are:

To the United States Government:

- Vigorous and large expansion of National Science Foundation and other Federal programs to upgrade the quality of science instruction through direct service to teachers.
- Expansion of Federal support of research and development in the use of computers and other information technologies in science education.
- Expansion of Federal support for research in science education.
- Establishment of Federally supported Regional Science Centers as focal points for improvement of precollege science education.

To State agencies and curriculum bodies:

- Raising of teacher certification standards in science and mathematics, in both elementary and secondary schools, and national adherence to such standards.
- Increase in the amount and level of science and mathematics taught to all students.
- Improvements in teacher compensation and in conditions of employment.

To Scientific Societies:

- Formation of a National Council on Education in Science and Technology to coordinate and oversee national educational efforts, with emphases on public understanding of science and on precollege education.

To the Chemical Industry:

- Strengthening and expansion of activities that bring the resources of the chemical industry to bear on improvement and support of science education at all levels.

To the American Chemical Society:

- Creation of a 5-year plan to improve chemistry education nationwide in the high schools.
- Consideration of how best to characterize opportunities in chemistry and the expectations of employers, identify necessary curriculum and resource elements, and utilize results of research to improve chemistry education.
- Expansion of efforts to provide information on chemistry and chemical affairs to Congressional and administrative decision-makers.

To Secure Our Future
March 1989

The Federal Role in Education, a report of the National Center on Education and the Economy.

Identification: The National Center on Education and the Economy is a not-for-profit corporation "created to develop proposals for building the world class education and training system the United States must have if it is to have a world class economy." Members of the Board of Directors of the Center are leaders from corporations, foundations, higher education, public school systems, and state government.

The report accepts the widely acknowledged general findings of other studies as regards the condition of elementary and secondary education in the United States, and sets forth a detailed action plan. A strong underlying theme of the report is that "the current structure of federal programs has become part of the problem rather than of the solution."

Argument: "[It] is important to produce enormous gains in the skills of our people . . . [but] we do not propose large increases in federal funding for education . . . Education, like private industry, can improve by restructuring operations following some very simple principles. First, go for quality and build it in the first time whenever possible. Second, reward success in producing quality. Third, when a system for real accountability is in place, let the people on the firing line figure out how to get the job done, and get rid of as much of the bureaucracy and as many of the intervening rules and regulations as possible."

Goal: "We believe that only the President is in a position to establish a new American consensus on the need to build a world class system for education and training." "Only the President can set a goal for the nation: Americans are going to be the best in the world at educating and training our people, whatever it takes! The country must be challenged to make sure that by the year 2000, the United States—

- will overtake Singapore, now first in 12th grade biology, from our current ranking of dead last in a ranking of 13 countries.
- will overtake Canada and Norway, where 24-25 percent of 18 year olds take physics and chemistry for two years each, compared to less than one percent in the United States.
- will overtake Japan and Korea, now tied for first in general science for 10 year olds, from our current rank of number eight.
- will overtake Japan in the mastery of mathematics skills, which will require that our high school

graduates master more math than our college graduates do now.

- will provide those of our high school graduates not going directly to college with apprenticeship skills equal to or even better than those of their West German counterparts.
- will overtake the functional literacy rates of our leading competitors in Europe and Asia, now around 90%, from our current rate of about 70%.
- will [have] European and Asian managers coming here to find out how to train their workers . . . instead of our sending to Europe and Asia to find out how to train workers for high levels of productivity.
- will triple expenditures by American firms on the education and training of their workers, to equal the expenditures now made by their most able foreign competitors."

"The challenge is to provide an elite education for everyone."

Missions. To meet that challenge, the report proposes four missions: (1) Assure that every child starts school healthy and intellectually prepared; (2) Dedicate the country to restructuring elementary and secondary education for high performance; (3) Make our schools a showcase for the contributions that information technology can make to learning; (4) Provide a second chance to every American now in the workforce to get the skills they will need to contribute effectively in an information-based economy."

"America needs to be reassured that the federal government does not propose to take over responsibility for education." "The essential precondition for having the best education system in the world is national determination." "The way to begin is to get the incentives right, to make sure that there are appropriate rewards for success and real consequences for failure."

Recommendations. [The recommendations of the report appear in detailed descriptions of each of the four missions noted above.]

(1) PREVENT DAMAGE TO YOUNG CHILDREN

"Investment in quality child care and early childhood development pays handsome dividends in school and later in life. A broad consensus has developed for a greatly expanded federal role in this area, which we support." "The legislation should place a premium on encouraging states and localities to combine federal, state, and local resources for full time day care, preschool child development centers and before and after school care programs. In order for such coherent strategies to emerge it will be essential to strengthen the role of the state government in the Headstart Program." "[It] is also imperative to find a way to produce high national standards for day care centers and for the professionals who run them."

(2) RESTRUCTURE THE SCHOOLS FOR HIGH PERFORMANCE

"In the first instance, the object is to fill our schools with first rate teachers and administrators who themselves have [higher order thinking] skills and are capable of developing them in their students." "Secondly, it requires setting up performance oriented systems in which the goals for students are clearly specified, and rewards go to schools in which students make substantial progress toward those goals. Finally, it requires greatly reducing the bureaucracy in the system and giving much more authority to school staffs than they have ever had before to decide how to meet the needs of the students."

"Strategies must be devised for greatly improving teacher preparation and upgrading teacher licensure. Standards for student performance that reflect . . . higher order thinking skills must be developed and methods of measuring student progress against those standards must be devised for use at local levels. New accountability and incentive systems need to be designed and tested. Radically different approaches to organizing schools and districts, arranging for funds flows, monitoring system performance [etc.] must be designed and implemented. New conceptions of school administration and management must be devised and people trained to make them work."

"The aim of federal policy should be to create the conditions under which local people have strong incentives to meet the needs of students and maximum freedom to figure out how to produce those results."

Components of the restructuring program.

1. High Performance Schools . . . "[The program] would permit participants to combine funds provided by [specific federal programs]." "School districts involved in this program would be expected to engage in major efforts to restructure their schools for high performance . . . push decisions down to the school level, . . . give individual schools much more discretion over the way funds are spent, new salary and staffing systems that will enable them to attract and hold first rate teachers, . . . reduce bureaucracy to a minimum and [establish] new accountability systems that provide real rewards to school staffs that are able to produce substantial progress for their students."

2. A School to Work Transition [program] "would permit participants to combine funds from [several specific federal programs] focussing on dropout prevention . . . to break down current institutional barriers by providing strong incentives for the community to come together and provide coordinated service delivery systems. Participants would . . . involve school people and employers in the provision of job development, job counseling, and high level academic and vocational skills in one integrated program . . . agree to common academic and occupational competency standards . . . and common performance standards."

3. A Social Service Integration [program] "would permit a community to develop integrated strategies for the use of funds that now go separately from state and federal sources, . . . permit and encourage development of bold new solutions to the problems faced by low income communities, . . . which would be expected to commit to negotiated standards for client outcomes."

4. A State Assistance Initiative [would] "recognize the leadership the states have displayed . . . and allow them some flexibility in using the assistance they now receive for federal program administration to develop and implement policies needed to support school restructuring. [It] would provide funds enabling states to plan, design, implement and evaluate new policy systems that show substantial promise of greatly increasing the productivity of the state delivery system for education. . . [The] states would also be eligible for modest financial assistance to help them put in place the key elements required at the state level to make restructuring programs for the

professionalization of teaching work, including improved programs of teacher preparation; new recruitment, licensing and induction systems for teachers and principals; new accountability systems (including public choice plans and performance incentive plans); and new leadership development programs for key personnel at all levels of the state and local structure."

5. "More Emphasis on Statistical and Educational Research [is necessary] if the restructuring program is going to succeed. [Work is needed on] the attainment of people in the workforce, . . . assessment of what college students know and are able to do . . . [comparison of the] educational attainments of its school children, college students, and members of its workforce with those of other countries on a regular basis." "It is essential that valid, reliable and affordable assessments of a whole range of higher order thinking skills be devised and made available to the states and the schools as soon as possible, [along with] good measures of teacher performance. . . ."

(3) MAKE THE UNITED STATES PREEMINENT IN SCIENCE, MATHEMATICS AND TECHNOLOGY

1. Declare a Goal. "The President should declare a goal of matching the mathematics and science performance of students in all other countries by a date certain and create a cabinet council to devise a national strategy for doing that, in concert with the science community and the science education community."

2. Develop New Curriculum Resources. "[A] new science, mathematics, and technology curriculum development effort should be announced, designed to engage the country's most talented mathematicians, scientists, engineers and teachers in a determined effort to produce curriculum materials and teaching materials that will support the teaching of challenging technical curricula not just to a small elite, but to the vast majority of American students. This program should be complemented by an even larger effort to improve radically the quality of mathematics and science teachers and teaching, especially in the elementary grades."

3. Build a National Communications Highway for Education. "The administration should announce as soon as possible its commitment to engage the talents of the military and the high technology business community in the construction of a national communications network that could be used by students of all ages for the delivery and exchange of television and computer-based instruction and information."

4. Create a Laboratory of Networked Demonstration Schools. "At the same time a new program should be announced, creating a network of schools around the country that will be laboratories and demonstration sites for the application of advanced information technologies to education."

5. Design a National Program to Teach Teachers Technology. "[The] states should be used to design a national program to train teachers to use these new technologies effectively."

(4) PROVIDE OUR WORKERS THE SKILLS THEY NEED TO COMPETE

1. Adult Literacy, though a personal misfortune, is a threat to the nation's standard of living. "Attention must be paid to strengthening the second chance system for those who did not get a basic education in school and who are, as a result, living on the economic and social margins of our society."

2. Higher Levels of Workforce Training. "Some nations with which we compete have long established corporate cultures that support high levels of private expenditures to address some of these problems for some of the members of the workforce. Others rely on various forms of tax abatements to finance these functions while others rely on taxes to raise very substantial revenues for direct government expenditures for the same purposes. We should explore all of these options and construct a policy for the United States that suits our needs and cultural and political character."

The Science Report Card September 1988

Report of Science Achievement in the 1986 National Assessment of Educational Progress.

Identification: NAEP is an ongoing, congressionally-mandated project established to determine and report the status and trends over time of educational achievement. Beginning in 1969, NAEP has assessed 9-, 13-, and 17-year-olds attending public and private schools. Assessments of science achievement were made in 1969-70, 1972-73, 1976-77, 1981-82, and 1985-86.)

Content: Each science assessment comprises a range of open-ended and multiple-choice questions measuring performance on sets of objectives developed by nationally-representative panels of science specialists, educators, and concerned citizens. The questions range across the life sciences, chemistry, physics, earth and space science, and history of science; involve contexts such as the scientific, personal, societal, and technological; and cognitive areas such as knowledge use, and integration. A small fraction of the questions is carried from assessment to assessment in order to anchor the results across time.

Scores and Trends: (Scores are rounded to whole numbers; 95% confidence interval is approximately plus-or-minus 1; range is 0 - 500. Averages may be interpreted as follows: "150 - Knows everyday science facts; 200 - Understands simple scientific principles; 250 - Applies basic scientific information; 300 - Analyzes scientific procedures and data; 350 - Integrates specialized scientific information.")

	1970	1973	1977	1982	1986
Age 9, All	225	220	220	221	224
Age 13, All	255	250	247	250	251
Age 17, All	305	296	290	283	289

At every age, scores of male students are slightly higher than those of females. The differences in 1986, for example, were: Age 9, 6 points; Age 13, 9 points; Age 17, 13 points (the 95% error in these figures is about 2 points). At every age, black and hispanic students have lower scores than white students. The differences for black students in 1986, for example, were: Age 9, 36 points; Age 13, 37 points; Age 17, 45 points (the 95% error in these figures is about 3 points).

Findings: Age 9: The slight decline of the early '70s has been reversed and "the average proficiency of 9-year-olds in 1986 returned to that of the first science assessment in 1970." Age 13: Trend similar to that at Age 9, "although . . . performance appears to have declined more and recovered less." Age 17: The steady decline from 1970 appears to end in 1982, with significant less-than-catch-up improvement in 1986.

As to gender-related score trends: "The performance gap between males and females at age 9 has increased somewhat across time," that at age 13 has more than doubled; that at age 17 has decreased slightly.

As to ethnicity-related score trends: "Although substantially larger gains by black and hispanic students (in 1986) served to narrow their performance gaps relative to white students, the remaining disparities are a serious concern. Minority students at ages 13 and 17 still appear to perform, on average, at least four years behind their majority counterparts."

". . . trends in science proficiency suggest that a majority of 17-year-olds are poorly equipped for informed citizenship and productive performance in the workplace, let alone postsecondary studies in science."

"Because elementary science instruction tends to be weak, many students . . . are inadequately prepared for middle-school science. The failure they experience in middle school may convince these young people that they are incapable of learning science, thus contributing to the low enrollment in high-school science courses. Unless conditions in the nation's schools change radically, it is unlikely that today's 9- and 13-year-olds will perform much better as 17-year-olds tomorrow."

Conclusions. ". . . improvements in average performance seen in the 1986 assessment were largely the result of students' increased knowledge about science rather than increased skills in scientific reasoning.

"The need for greater availability of classroom laboratory facilities is undeniable . . . a substantial percentage of teachers do not have access to adequate laboratories, science equipment, supplies, and other resources needed for teaching science. Perhaps even more crucial than greater access to laboratory facilities are the more fundamental, but less obvious, changes associated with teaching and curriculum" . . . e.g., "to teach an array of disciplines over a period of years, maintaining continuity across the grades."

". . . both the content and structure of our school science curricula are generally incongruent with the ideals of the scientific enterprise. . . . our nation is producing a generation of students who lack the intellectual skills necessary to assess the validity of evidence or the logic of arguments, and who are misinformed about the nature of scientific endeavors."

The Mathematics Report Card June 1988

Report of Mathematics Achievement in the 1986 National Assessment of Educational Progress.

Identification: NAEP is an ongoing, congressionally-mandated project established to determine and report the status and trends over time of educational achievement. Beginning in 1969, NAEP has assessed 9-, 13-, and 17-year-olds attending public and private schools. Assessments of mathematics achievement were made in 1972-73, 1977-78, 1981-82, and 1985-86.)

Content: Each mathematics assessment comprises a range of open-ended and multiple-choice questions measuring performance on sets of objectives developed by nationally-representative panels of science specialists, educators, and concerned citizens. The questions cover a range of content (e.g., numbers

and operations, measurement, geometry, and algebra) and process areas (e.g., knowledge, skills, applications, and problem solving). A small fraction of the questions is carried from assessment to assessment in order to anchor the results across time.

Scores and Trends: (Scores are rounded to whole numbers; 95% confidence interval is approximately plus-or-minus 1; range is 0 - 500. Averages may be interpreted as follows: "150 — Simple arithmetic facts; 200 — Beginning skills and understanding; 250 — Basic operations and beginning problem solving; 300 — Moderately complex procedures and reasoning; 350 — Multi-step problem solving and algebra.")

	1973	1978	1982	1986
Age 9, All	219	219	219	222
Age 13, All	266	264	269	269
Age 17 All	304	300	299	302

At age 9, scores of female students are slightly higher than those of males, except in the most recent assessment. The differences in 1986, for example, were: Age 9, 0 points; Age 13, 2 points; Age 17, 5 points (the 95% error in these figures is about 2 points). At every age, black and hispanic students have lower scores than white students. The differences for black students in 1986, for example, were: Age 9, 20 points; Age 13, 24 points; Age 17, 19 points (the 95% error in these figures is about 3 points).

Findings: Age 9: There was a slight improvement in performance on the 1986 assessment. Age 13: A slight decline in the 70s was more than overcome in 1981-82, but not further in 1985-86. Age 17: The modest decline through 1981-82 may have been ended, but not erased, by slight improvement in 1985-86.

As to gender-related score trends: "The slight performance superiority at age 9 of females with respect to males disappeared in the 1985-86 assessment, while that at age 13 disappeared in 1975-76. Among 17-year-olds, the 8 point superiority of males was halved in 1977-78 and has remained at that size.

As to ethnicity-related score trends: Except for hispanic 9-year-olds, both black and hispanic students have shown significant improvements in performance since 1977-78, though the gains are not steady. Although these substantial gains by black and hispanic students served to narrow their performance gaps relative to white students, the remaining disparities are a serious concern. Minority students at ages 13 and 17 still appear to perform, on average, at least four years behind their majority counterparts.

Most of the improvement shown appears to have "resulted from increased performance in low-level skills." "The highest level of performance . . . reflects only moderately complex skills and understandings."

". . . the curriculum appears to be dominated by paper-and-pencil drills on basic computation. Little evidence appears of any widespread use of calculators, computers, or mathematics projects." "There is little concern with students' "understanding of concepts and development of higher-order thinking skills." " . . . students' enjoyment of and confidence in mathematics appear to wane as they progress through their schooling. Most perceive that the subject is composed mainly of rule memorization, and expect to have little use for mathematical skills in their future work lives."

Conclusions: "Achieving a higher-quality mathematics curriculum . . . will require new materials, effective instructional methods, and improved means of evaluating student performance." "No longer can society afford to view mathematics as a subject for a chosen few or as a domain solely composed of arithmetic skills. Students must come to see it as a way of thinking, communication, and resolving problems. Until American schools move toward these more ambitious goals in mathematics instruction, there is little hope that current levels of achievement will show any appreciable gain."

A World of Differences
January 1989

Report of an International Assessment of Mathematics and Science.

Identification: This is a pair of multi-national studies based on test items drawn from the Mathematics and Science components of the 1985-86 National Assessment of Educational Progress (see the previous two summaries). The students (several thousand from each population) were all 13-year-olds attending both public and private elementary, middle, and secondary schools. Student populations were sampled in the United States, United Kingdom, Spain, Korea, British Columbia, and Ireland; (F)French- and (E)English-speaking students were tested separately in New Brunswick, Ontario, and Quebec.

Content: Back-translations of all items from other languages were compared with the English originals in establishing the accuracy of translation. Units of measurement, names of children, and species of plants and animals were changed to reflect local usage.

Part I: Mathematics

Scores: Adjusted scores, relative to an hypothetical ideal or perfect "level" of 1000, are interpreted thus: 300 - Performs simple addition and subtraction; 400 - Use basic operations to solve simple problems; 500 - Use intermediate level mathematics skills to solve two-step problems; 600 - Understand measurement and geometry concepts and solve more complex problems; 700 - Understand and apply more advanced mathematical concepts.

Findings: Average scores for all students break into four groups (one is Korea alone); differences between groups are statistically significant, differences within groups are not:

Entity	Average
Korea	568
Quebec(F)	543
British Columbia	540
Queensland(E)	536
New Brunswick(E)	529
Ontario(E)	516
New Brunswick(F)	514
Spain	512
United Kingdom	510
Ireland	504
Ontario(F)	482
United States	474

Only for Korea and Spain was a significant difference found between the average performance of male and female students.

The following data show the percentages of selected populations performing at or above the 400 to 700 Levels of the scale; the highest, median, and lowest scoring populations are shown.

Level	Highest	Median	Lowest
400	97% Quebec	95% Korea Br. Columbia New Brnswk.	78% U.S.
500	78% Korea	58% Ontario(E) New Brnswk(F)	40% U.S.
600	40% Korea	16% Ontario(E) 12% New Brnswk(F)	9% U.S.
700	5% Korea	2% to 1%, ten populations	0% Ontario(F)

There is virtually no correlation between entity average score and the distribution of time over various classroom activities (e.g., listening to teacher explanations, working problems alone, working problems in small groups, getting or giving help).

In most populations, increased homework correlates with higher average score, but the effect does not explain the entity-to-entity differences.

The spread of average scores on the six groups of topical questions is about the same, relatively, as that of the overall score. The following are the highest, lowest, and U.S. average percents correct in each area:

Topic	Highest	Lowest	U.S.
Numbers and operations	78%	62%	62%
Relations, functions, algebra	80%	60%	60%
Geometry	73%	48%	50%
Measurement	72%	43%	43%
Data organization & interpretation	75%	50%	57%
Logic and problem solving	79%*	60%	67%

* United Kingdom. Korea highest on all other topics.

Part II: Science

Scores: Adjusted scores, relative to an hypothetical ideal or perfect "level" of 1000, are interpreted thus: 300—Know everyday science facts; 400—Understand and apply simple scientific principle; 500—Use scientific procedures and analyze scientific data; 600—Understand and apply intermediate scientific knowledge and principles; 700—Integrate scientific information and experimental evidence.

Findings: Average scores for all students break into three groups; differences between groups are statistically significant, differences within groups are not:

Entity	Average
British Columbia	551
Korea	550
United Kingdom	520
Quebec(E)	515
Ontario(E)	515
Quebec(F)	513
New Brunswick(E)	511
Spain	504
United States	479
Ireland	469
Ontario(F)	468
New Brunswick(F)	468

Male students outperform female students in all populations, but the difference is not statistically significant in the United States and United Kingdom. The differences are far greater in science than in mathematics (see previous summary).

The following data show the percentages of selected populations performing at or above the 400 to 700 Levels of the scale; the highest, median, and lowest scoring populations are shown.

Level	Highest	Median	Lowest
400	95% Br. Col.	90% New Brnswk.(E) 89% United Kingdom	70% Ireland
500	73% Korea	58% Ontario(E)	35% Ontario(F) NewBrnswk(F)
600	33% Korea	15% Quebec New Brnswk(E)	7% N.Brnswk(F)
700	4% Br. Col.	2% to 1%, ten populations	1% Ontario(F) NewBrnswk(F)

There is poor correlation between entity average score and the distribution of time over some classroom activities (e.g., reading the textbook, solving written science problems, watching a science film or TV program), but modest positive correlation with respect to experiment-related activities (watching teacher demonstrations, doing experiments alone or with other students).

Increased homework correlates with higher average score in only half the populations, but that set includes the top four.

The spread of average scores on the six groups of topical questions is about the same, relatively, as that of the overall score. The following are the highest, lowest, and U.S. average percents correct in each area:

Topic	Highest	Lowest	U.S.
Life sciences	73%*	58%	64%
Physics	65%*	53%	53%
Chemistry	65%*	48%	51%
Earth and space sciences	74%	56%	63%
Nature of science	67%	54%	56%

* Korea. British Columbia highest on other topics.

Science Achievement in Seventeen Countries 1988

Report of preliminary results from a 1983-86, multi-nation study by the International Association for the Evaluation of Educational Achievement.

Identification: The report present preliminary results from 17 countries in the 24-nation, 1983-86 survey of science achievement by students at three levels in each school system: 10-year-old level ("Grade 5"); 14-year-old level ("Grade 9"); and the final year of secondary school ("Grade 12").

Content: The tests comprised items appropriate to each grade level from a comprehensive set covering 57 agreed, common topical areas in earth and space sciences, biology, chemistry, and physics. Examination of individual national and regional curricula coupled with extensive preliminary testing assured

high validity of the final tests. The Grade 5 and Grade 9 level tests were administered to whole school populations; the Grade 12 level tests were administered to "specialists"—students who, in their final year of school, were enrolled in their second year of study of Physics, Chemistry, or Biology (in the U.S., this group comprises those enrolled in "Advanced Placement" courses).

Sample: The application unit was the individual school. The numbers of school participating in each country ranged from 64 in Sweden, through 123 in the U.S., to 463 in the Philippines. Numbers of students tested in each country ranged widely. The ranges were Grade 5, 1305-16851 (U.S. 2822); Grade 9, 1420-10874 (U.S. 2519); Grade 12 - Physics, 398-6025 (U.S. 537); Chemistry, 143-6018 (U.S. 659); Biology, 147-5960 (U.S. 659).

Findings, Grade 5. The mean percent correct on the 24-item test is listed here:

Japan	64.2
Korea	64.2
Finland	63.8
Sweden	61.3
Hungary	60.0
Canada (Eng.spkng.)	57.1
Italy	55.8
United States	**55.0**
Australia	53.8
Norway	52.9
Poland	49.6
England	48.8
Singapore	46.7
Hong Kong	46.7
Philippines	39.6

Thirty-eight percent of U.S. schools had mean scores lower than the lowest mean score reported from Japan. Fourteen percent of the variance of U.S. mean scores is between schools, while 86 percent is between students within schools; that is, variation in science achievement at Grade 5 is much less school-dependent in the U.S. than it is student-dependent.

U.S. students scored about 8 percentage points higher on physical science items than on life science items. Twenty-one items on the test were identical with items used in a 1970 assessment; U.S. students performed on these about the same in 1986 as in 1970.

Male students scored higher than female students in all countries. The average difference was 3.6 percentage points and ranged from 0.8 percentage point (Philippines), through 5.0 (U.S.) to 7.6 (Norway).

Findings, Grade 9. The mean percent correct on the 80-item test is listed here:

Hungary	72.3
Japan	67.3
Netherlands	66.0
Canada (Eng.spkng)	62.0
Finland	61.7
Sweden	61.3
Poland	60.3
Korea	60.3
Norway	59.7
Australia	59.3
England	55.7
Italy	55.7
Thailand	55.0
Singapore	55.0
United States	**55.0**
Hong Kong	54.7
Philippines	38.3

Thirty percent of U.S. schools had mean scores lower than the lowest mean score reported from Hungary. Thirty percent of the variance of U.S. mean scores is between schools, while 70 percent is between students within schools; that is, variation in science achievement at Grade 9 is more school-dependent in the U.S. than at Grade 5, but still largely student-dependent.

U.S. students scored about 13 percentage points higher on life science items than on physical science items. Twenty items on the test were identical with items used in a 1970 assessment; U.S. students performed less well on these in 1986 than in 1970. The U.S. ranked 7th among 17 nations in 1970, compared with 15th among 17 in 1986.

On a set of items common to both tests, Grade 9 student scores averaged 19 percentage points higher than those of Grade 5 students.

Male students scored higher than female students in all countries, as they did in 1970. The average difference was 5.3 percentage points (down from 7.0 in 1970) and ranged from 2.1 percentage points (Hungary), through 6.1 (U.S.) to 7.7 (Netherlands).

Findings, Grade 12: Physics. The mean percent correct on the test (26 items in the U.S., 30 elsewhere) is listed here:

Hong Kong (Form 7)	69.9
Hong Kong (Form 6)	59.3
England	58.3
Japan	56.1
Singapore	54.9
Norway	52.8
Poland	51.5
Australia	48.5
United States	**45.5**
Sweden	44.8
Canada (Eng.spkng.)	39.6
Finland	31.0
Italy	28.0

Eighty-nine percent of U.S. schools had mean scores lower than the lowest mean score reported from Hong Kong (Form 7). Thirty-eight percent of the variance of U.S. mean scores is between schools, while 62 percent is between students within schools; that is, variation in achievement in second-year Physics in the U.S. is due almost as much to differences between schools as it is to differences between students. Further, school-to-school differences in science education increase substantially with grade level.

On a comparable test administered in 1983 to U.S. first-year Physics students, the average score was 34 percent.

Male students scored higher than female students in all countries. The average difference was 5.8 percentage points and ranged from 0.6 percentage point (England), through 6.6 (U.S.) to 8.8 (Netherlands).

Findings, Grade 12: Chemistry. The mean percent correct on the test (25 items in the U.S., 30 elsewhere) is listed here:

Hong Kong (Form 7)	77.0
England	69.3
Singapore	66.1
Hong Kong (Form 6)	64.4
Japan	51.9
Hungary	47.7
Australia	46.6
Poland	44.6
Norway	41.9
Sweden	40.0
Italy	38.0
United States	**37.7**
Canada (Eng.spkng.)	36.9
Finland	27.2

Forty-eight percent of U.S. schools had mean scores lower than the lowest mean score reported from Hong Kong (Form 7). Forty-nine percent of the variance of U.S. mean scores is between schools, while 51 percent is between students within schools; that is, variation in achievement in second-year Chemistry in the U.S. is due just as much to differences between schools as it is to differences between students.

Male students scored higher than female students in all countries. The average difference was 5.4 percentage points and ranged from 0.6 percentage point (Sweden), through 6.3 (U.S.) to 10.4 (Netherlands).

Findings, Grade 12: Biology. The mean percent correct on the test (25 items in the U.S., 30 elsewhere) is listed here:

Singapore	66.8
England	63.4
Hungary	59.7
Poland	56.9
Hong Kong (Form 7)	55.8
Norway	54.8
Hong Kong (Form 6)	50.8
Finland	48.9
Sweden	48.5
Australia	48.2
Japan	46.2
Canada (Eng.spkng.)	45.9
Italy	42.3
United States	**37.9**

Ninety-eight percent of U.S. schools had mean scores lower than the lowest mean score reported from Singapore. Forty percent of the variance of U.S. mean scores is between schools, while 60 percent is between students within schools; that is, variation in achievement in second-year Biology in the U.S. is due almost as much to differences between schools as it is to differences between students.

Male students scored higher than female students except in Hong Kong (Form 7) and Sweden; in Australia their average scores were indistinguishable. The average difference was 3.4 percentage points and ranged from 2.6 percentage points (Sweden), through 5.2 (U.S.) to 7.4 (Singapore).

Among U.S. students in Grade 12, females who were taught physics and chemistry by male teachers performed better on the average than those taught by female teachers; both male and female students in biology performed better on the average if their teachers were female.

Science for All Americans (Project 2061) 1989

Report of the first of three phases of a decade-long K-12 science curriculum reform project undertaken by the American Association for the Advancement of Science (AAAS).

Identification: "Science for All Americans" is a report on the first of three phases in a major kindergarten-through-high-school resynthesis of the school science curriculum. Its driving concern is for the improvement of the ability and capacity of the educational "system" to send forth future citizens who are "science literate."

Project Structure: Phase I (completed) "has established a conceptual base for reform by defining the knowledge, skills, and attitudes all students should acquire as a consequence of their total school experience from kindergarten through high school. That conceptual base consists of recommendations presented in Science for All Americans and the reports of five discipline-oriented panels.

In Phase II (underway), "teams of educators and scientists are transforming these (summary and panel) reports into blueprints for action . . . to produce a variety of alternative curriculum models that school districts and states can use as they undertake to reform the teaching of science, mathematics, and technology. Phase II will also specify the characteristics of reforms needed in other areas . . . teacher education, testing policies and practices, new materials and modern technologies, the organization of schooling, state and local policies, and research.

"In Phase III, the project will collaborate with scientific societies, educational associations and institutions, and other groups . . . in a nationwide effort to turn the Phase II blueprints into educational practice."

Disciplinary Panels: The basic work of Phase I was done by five discipline-oriented panels, "each composed of 8-10 scientists, mathematicians, engineers, physicians, and others known to be accomplished in their fields and disciplines and to be fully conversant with the role of science, mathematics, and technology in the lives of people."

All panels were charged to answer a single basic question: What is the (name of discipline) component of scientific literacy? The answer was required to be conditioned as follows: Focus on scientific/mathematical significance; Apply considerations of human significance; Begin with a clean slate; Ignore the limitations of present-day education; Identify only a small core of essential knowledge and skills; Keep in mind the target population—all students.

The five panels dealt with: Biological and Health Sciences; Mathematics; Physical and Information Sciences and Engineering; Social and Behavioral Sciences; Technology. Panel reports (which are available as supplements to the full report) describe the (name of discipline) component of scientific literacy through brief essays in 30 to 50 pages of small type.

For example, the report of the Biological and Health Sciences Panel comprises the following sections: Rationale; A Conceptual Framework for Biology; Human Biology; The Evolution of Diverse Life-Forms; Environmental Biology; and Human Ecology.

The National Council: A 26-person National Council on Science and Technology Education was formed by the AAAS. Its distinguished members included scientists and technologists from many disciplines, educators, and public officials.

The basic question posed to the Council was: "Out of all the possibilities, what knowledge, skills, and habits of mind associated with science, mathematics, and technology should all Americans have by the time they leave school?" The answer was to be constrained as follows: "Consider the question from base zero. Consider possibilities across all of science, mathematics, and technology; Come up with learning goals that are modest enough to make sense for all students; Study the reports of the scientific panels carefully and take into account other viewpoints as well."

The bulk of the subject report, some 120 pages, consists of the Council's recommendations in essay form. The material is organized into four categories:

> The Scientific Endeavor—the nature of science, mathematics, and technology as human enterprises (The Nature of Science; The Nature of Mathematics; The Nature of Technology);
>
> Scientific Views of the World—basic knowledge about the world as currently seen from the perspective of science and mathematics as shaped by technology (The Physical Setting; The Living Environment. The Human Organism; Human Society; The Designed World; The Mathematical World);
>
> Perspectives on Science—what people should understand about some of the great episodes in the history of the scientific endeavor and about some crosscutting themes that can serve as tools for thinking about how the world works (Historical Perspectives; Common Themes); and
>
> Scientific Habits of Mind—the habits of mind that are essential for scientific literacy (Habits of Mind).

A final Part of the report discusses the relationships of the work of Phase I to that contemplated by Phases II and III under the label "Bridges to the Future" (Effective Learning and Teaching; Reforming Education; Next Steps).

Curriculum and Evaluation Standards for School Mathematics March 1989

Report of the Working Groups of the Commission on Standards for School Mathematics of the National Council of Teachers of Mathematics (NCTM).

Identification: NCTM in 1986 charged its Commission of Standards for School Mathematics with two tasks: (1) to "Create a coherent vision of what it means to be mathematically literate in a world that relies on calculators and computers to carry out mathematical procedures, and in a world where mathematics is rapidly growing and is extensively being applied in diverse fields."; and (2) to "Create a set of standards to guide revision of the school mathematics curriculum and associated evaluation toward this vision." This report is the result of the effort to discharge that pair of tasks.

Scope: The report is a detailed blueprint of an up-to-date school mathematics curriculum extending from kindergarten through grade 12, including appropriate assessment/evaluation strategies. It "presents criteria to be used to *judge* the quality of the mathematics curriculum and methods of evaluation. The standards should be viewed as facilitators of reform, rather than as a set of directives. . . [They] give direction toward a set of national expectations while allowing and encouraging local initiatives."

Approximately 160 pages of the report are devoted to presentation of detailed curriculum standards for K-12 school mathematics; the following 60 pages provide similarly detailed descriptions of the evaluation standards for testing student achievement in formal educational exercises based on the curriculum standards.

Content: Curriculum Standards. The curriculum standards are presented in three clusters: Grades K-4, Grades 5-8, and Grades 9-12. After introductory discussion of the needs for and directions of change to be recommended, and of the assumptions of the working groups, the content for each cluster is stated in 13-14 formal standards. The breadth and sophistication of the standards are to be seen in their titles, which follow.

Grades K-4:
1. Mathematics as Problem Solving
2. Mathematics as Communication
3. Mathematics as Reasoning
4. Mathematical Connections
5. Estimation
6. Number Sense and Numeration
7. Concepts of Whole Number Operations
8. Whole Number Computation
9. Geometry and Spatial Sense
10. Measurement
11. Statistics and Probability
12. Fractions and Decimals
13. Patterns and Relationships

Grades 5-8:
1. Mathematics as Problem Solving
2. Mathematics as Communication
3. Mathematics as Reasoning
4. Mathematical Connections
5. Number and Number Relationships
6. Number Systems and Number Theory
7. Computation and Estimation
8. Patterns and Functions
9. Algebra
10. Statistics
11. Probability
12. Geometry
13. Measurement

Grades 9-12:
1. Mathematics as Problem Solving
2. Mathematics as Communication
3. Mathematics as Reasoning
4. Mathematical Connections
5. Algebra
6. Functions
7. Geometry from a Syntheic Perspective
8. Geometry from an Algebraic Perspective
9. Trigonometry
10. Statistics
11. Probability
12. Discrete Mathematics
13. Conceptual Underpinnings of Calculus
14. Mathematical Structure

Content: Evaluation Standards.

After introductory comments on the critical relationships between the contents of the curriculum and of the instruments employed to test achievement by those who are learning through the curriculum, fourteen standards for evaluation and assessment are described in detail.

1. Alignment
2. Multiple Sources of Information
3. Appropriate Assessment Methods and Uses
4. Mathematical Power
5. Problem Solving
6. Communication
7. Reasoning
8. Mathematical Concepts
9. Mathematical Procedures
10. Mathematical Disposition
11. Indicators for Program Evaluation
12. Curriculum and Instructional Resources
13. Instruction
14. Evaluation Team

Implementation: The final section of the report is a brief description of the steps necessary to implement the "framework for curriculum development" it presents. The subsections deal with the following areas, all of which must be addressed if the desired curriculum reform is to be achieved: Curriculum Development; Textbooks and Other Materials; Tests; Instruction; Teacher In-Service Programs; Teacher Education; Technology; Students with Different Needs and Interests; Equity; Working Conditions; and Research.

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Everybody Counts 1989

A Report to the Nation on the Future of Mathematics Education—by the Mathematical Sciences Education Board (MSEB), Board on Mathematical Sciences (BMS), and Committee on the Mathematical Sciences in the Year 2000, of the National Research Council (NRC).

Identification: "The Mathematical Sciences Education Board was established in 1985 to provide a continuing national overview and assessment capability for mathematics education and is concerned with excellence in mathematics education at all levels. MSEB reports directly to the Governing Board of the NRC."

The Board on Mathematical Sciences is a part of the Commission on Physical Sciences, Mathematics, and Resources, within the National Research Council. The objectives of the BMS are "to maintain awareness and active concern for the health of the mathematical science and to serve as the focal point in the Research Council for issues connected with research in the mathematics sciences."

The Committee on the Mathematical Sciences in the Year 2000 was appointed at the beginning of 1988. It is a joint project of the MSEB and BMS, and is "to provide a national agenda for revitalizing mathematical sciences education in U.S. colleges and universities."

This report presents the results of three years' effort by the MSEB. Contributions to this work were made by "classroom teachers; college and university faculty and administrators; research mathematicians and statisticians; scientists and engineers; mathematics supervisors; principals; school superintendents; chief state school officers; school board members; members of state and local governments; and leaders of parent groups, business, and industry"—by more than 70 persons, in all.

Characteristics: Unlike others, this report "examines mathematics education as all one system, from kindergarten through graduate school; it treats all the major components of the system, from curricula, teachings, and assessment to human resources and national needs; it does not merely identify problems, but also charts a general course for the future, outlining a national strategy for pursuing that course; and, it is not the final report of a commission, but the beginning of a process through which teachers, state and local authorities, and the varied constituencies of mathematics education can draw together in a sustained revitalization effort."

Content: In 80 pages, the report examines aspects of, and the problems and opportunities in, the universe of mathematics education, under these headings:

Opportunity: tapping the power of mathematics; Human resources: investing in intellectual capital Mathematics: searching for patterns; Curriculum: developing mathematical power; Teaching: learning through involvement; and Change: mobilizing for curriculum reform.

Findings: The general findings of the study are encapsulated in seven statements of "Transitions":

"The focus of school mathematics is shifting from a dualistic mission (minimal mathematics for the majority, advanced mathematics for a few) to a singular focus on a significant common core of mathematics for all students.

"The teaching of mathematics is shifting from an authoritarian model based on 'transmission of knowledge' to a student-centered practice featuring 'stimulation of learning.'

"Public attitudes about mathematics are shifting from indifference and hostility to recognition of the important role that mathematics plays in today's society.

"The teaching of mathematics is shifting from preoccupation with inculcating routine skills to developing broad-based mathematical power.**

"The teaching of mathematics is shifting from emphasis on preparation for future courses to greater emphasis on topics that are relevant to students' present and future needs.

"The teaching of mathematics is shifting from primary emphasis on paper-and-pencil calculations to full use of calculators and computers.

"The public perception of mathematics is shifting from that of a fixed body of arbitrary rules to a vigorous active science of patterns."

Each of these Transitions is then elaborated by means of additional, detailed findings. As an example, the detail for Transition 4 (** above) is quoted in its entirety.

"Mathematical power requires that students be able to discern relations, reason logically, and use a broad spectrum of mathematical methods to solve a wide variety of non-routine problems. The repertoire of skills which now undergird mathematical power includes not only some traditional paper-and-pencil skills, but also many broader and more powerful capabilities. Today's students must be able to:

"Perform mental calculations with proficiency;

Decide when an exact answer is needed and when an estimate is more appropriate;

Know which mathematical operations are appropriate in particular contexts;

Use a calculator correctly, confidently, and appropriately;

Estimate orders of magnitude to confirm mental or calculator results;

Use tables, graphs, spreadsheets, and statistical techniques to organize, interpret, and present numerical information;

Judge the validity of quantitative results obtained by others;

Use computer software for mathematical tasks;

Formulate specific questions from vague problems; (and)

Select effective problem-solving strategies."

Recommendations: Many of the very large number of detailed statements organized under the seven Transitions have the force of recommendations. In addition, the final chapter of the report, Action: moving into the 21st century, provides additional recommendation in the following guises: descriptions of National Goals, ways of Reaching Consensus, a National Strategy, specific Support Structures, and of

the elements of Leadership in various sectors. As examples, the elements of leadership for three constituencies are quoted below:

"Students:
Study mathematics every school year.
Discover the mathematics that is all around us.
Use mathematics in other classes and in daily life.
Study a broad variety of mathematical subjects."

"School Boards:
Establish appropriate standards for mathematics.
Align assessment with curricular goals.
Support innovation and professional development.

"Congress:
Stress education as an essential investment.
Support mathematics education at all levels.
Reward effective programs.

(The other constituencies addressed in this final section are: Teachers; Parents; Principals; Superintendents; Community Organizations; State School Officers; College and University Faculty; College and University Administrators; Business and Industry; State Legislators; Governors; and The President.)

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COMMITMENT AND COOPERATION AMONG PUBLIC RESEARCH UNIVERSITIES

The Alliance for Undergraduate Education is a cooperative project of major public research universities aimed at improving the quality of undergraduate education. Because of their size and scope, the participating universities provide academic environments that encourage the development of new ideas and programs. All are providing undergraduate education to large numbers of students in a context that includes graduate and professional education, basic and applied research, and service as an extension of teaching and research.

Officially formed in 1986, the Alliance office is located at The Pennsylvania State University. Support for the work of the Alliance comes from dues of member institutions and extramural grants.

Founding members of the Alliance are the University of California, Berkeley; the University of California, Los Angeles; The University of Illinois; the University of Maryland, College Park; The University of Michigan; the University of Minnesota; the University of North Carolina at Chapel Hill; The Ohio State University; The University of Texas at Austin; the University of Washington; and the University of Wisconsin–Madison. In July 1990, these founding members were joined by the University of Arizona, the University of Florida, Indiana University, and Rutgers, the State University of New Jersey.

The Alliance has as its primary goals the sharing of information on successful approaches in undergraduate education, the stimulation of new approaches to undergraduate programs, the development and dissemination of exemplary standards and practices for undergraduate education, and collaboration on program development and research projects about undergraduate education in research universities.

In addition to undergraduate science education, general areas of interest for the Alliance include writing instruction and assessment, selection and training of teaching assistants, alternative approaches to general education, recruitment and retention of minority students, cooperative relationships with secondary schools, assessment of undergraduate learning, academic advising, involvement of undergraduates in research, evaluation of teaching, and models for universitywide honors programs.

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